WSRC-RP-2001-00940

Key Words:
Super Compactor
Dynamic Compaction
Low-Level Waste Disposal

Retention:
Permanent

WASTE SUBSIDENCE POTENTIAL VERSUS SUPERCOMPACTION DIRECT PUCK DISPOSAL SUPPLEMENT

Mark A. Phifer

Elmer L. Wilhite

OCTOBER 5, 2001

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-96SR18500

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REVIEWS AND APPROVALS

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1.0 EXECUTIVE SUMMARY

Solid Waste Division (SWD) disposes of some low-level waste within specially-designed concrete vaults. Since the vaults are expensive to design and construct, SWD began utilization of a Waste Sort Facility / Super Compactor Facility to reduce the volume of waste placed in the vaults and thus extend the operational life of the vaults. Recently it was determined that some of the wastes previously disposed in the vaults could be safely disposed in trenches, which are much less expensive to design and construct. The Waste Sort Facility/ Super Compactor Facility operational cost is significant relative to the cost of trench design, construction, and operation. Therefore, Solid Waste Division requested the Savannah River Technology Center to conduct an evaluation to determine if Waste Sort Facility / Super Compactor Facility operation was cost efficient for waste disposed in trenches rather than vaults. The initial study conducted by the Savannah River Technology Center in response to the Solid Waste Division request is documented in Phifer and Wilhite (2001), Waste Subsidence Potential versus Supercompaction.

Within the previous study (Phifer and Wilhite, 2001), the waste pucks, produced from compaction of low density waste in 55-gallon drums within the Super Compactor Facility, were assumed to be placed in B-25 boxes for disposal in the Engineered Trench. This placement of a round puck in a rectangular box reintroduced some of the subsidence potential that was eliminated by use of the Super Compactor Facility. Therefore, the Solid Waste Division requested the Savannah River Technology Center to perform a sensitivity analysis to evaluate the optimal subsidence treatment achievable through use of the Super Compactor Facility. This additional evaluation assumes that rather than placing the pucks in B-25 boxes for disposal that the pucks are directly disposed (i.e., emplacement without the use of a container) within the Engineered Trench. While this method of disposal represents the optimal subsidence treatment achievable through use of the Super Compactor Facility, the Solid Waste Division does not consider it a realistic disposal option due to associated contamination control and personnel safety concerns.

The three supplemental waste/subsidence treatment methods, involving direct puck disposal, include:

- A Waste Sort Facility / Super Compactor Facility processing case
- A case involving both Waste Sort Facility / Super Compactor Facility processing and standard dynamic compaction
- A case involving both Waste Sort Facility / Super Compactor Facility processing and tertiary dynamic compaction

Conclusions of this supplemental study include:

- Direct puck disposal reduces the relative subsidence potential over all the corresponding cases evaluated in Phifer and Wilhite (2001).
- Tertiary dynamic compaction case presented in Phifer and Wilhite (2001) has the lowest short-term costs (total relative closure cost).
- Direct puck disposal results in lower long-term maintenance cost over all the corresponding cases evaluated in Phifer and Wilhite (2001).
- The case with the lowest total cost depends upon which subsidence repair method is utilized. If the traditional subsidence repair method is utilized, the direct disposal case, involving both Waste Sort Facility / Super Compactor Facility processing and tertiary dynamic compaction, is lowest. However, if the cap replacement method is utilized, the tertiary dynamic compaction case evaluated in Phifer and Wilhite (2001) is lowest.
- The direct puck disposal case, involving both Waste Sort Facility / Super Compactor Facility processing and tertiary dynamic compaction, represents the optimal subsidence treatment that can possibly be achieved with supercompaction. However this case still has a significant remaining subsidence potential of 5.5 feet, which is due to disposal of uncompactable waste in B-25 boxes. This continues to support the previous conclusion in Phifer and Wilhite (2001) that the use of B-25 boxes results in large inherent subsidence potential which cannot be totally eliminated by any of the methods evaluated. All of the waste/subsidence treatment methods evaluated are simply efforts that try to reduce the subsidence impacts created by the use of B-25 boxes.
- Overall this supplemental sensitivity study does not significantly change the conclusions and recommendations presented in Phifer and Wilhite (2001). Therefore, the Phifer and Wilhite (2001) conclusions and recommendations remain applicable.

Direct puck disposal significantly reduces the use of B-25 boxes. With direct puck disposal B-25 boxes are only utilized for the disposal of the uncompactable waste fraction. However the uncompactable waste fraction still represents a significant usage of B-25 boxes, and the direct puck disposal case still utilizes the Waste Sort Facility / Super Compactor Facility (WSF/SCF), which represents a significant short-term cost. The use of soft-sided bags (SSB), rather than the use of the WSF/SCF, for disposal of the compactable waste fraction may represent an opportunity to significantly decrease the short-term costs, while at the same time maintaining relatively low long-term costs. Evaluation of the SSB should continue and include an economic evaluation versus continued use of the WSF/SCF.

2.0 BACKGROUND

Solid Waste Division (SWD) disposes of some low-level waste within specially-designed concrete vaults. Since the vaults are expensive to design and construct, SWD began utilization of a Waste Sort Facility / Super Compactor Facility (WSF/SCF) to reduce the volume of waste placed in the vaults and thus extend the vaults' operational life. Recently, it was determined that some of the wastes previously disposed in the vaults could be safely disposed in trenches, which are much less expensive to design and construct. The WSF/SCF operational cost is significant relative to the cost of trench design, construction, and operation. Therefore the SWD requested the Savannah River Technology Center (SRTC) to conduct an evaluation to determine if WSF/SCF operation was cost efficient for waste disposed in trenches rather than vaults. The initial study conducted by SRTC in response to the SWD request is documented in Phifer and Wilhite (2001), Waste Subsidence Potential versus Supercompaction.

At the WSF/SCF, waste is sorted into low-density wastes (such as job control waste) and high-density wastes (such as wood and steel). Low density waste in 55-gallon drums is compacted in the Super Compactor Facility (SCF) and the resulting waste pucks are placed and stacked in B-25 boxes until each box is filled. Some low-density wastes, such as asbestos, PCB, and wetted waste, are not suitable for supercompaction. High-density waste such as wood and steel are placed in B-25 boxes in a manner to minimize void space.

Pre-sorted compactable waste is also received directly from the waste generators in 55-gallon drums, ready for supercompaction. Waste container data from the Waste Information Tracking System (WITS) on about 6,900 waste containers meeting the waste acceptance criteria for trench disposal was utilized to produce the WSF/SCF B-25 process flow diagram presented in Figure 1, which represents current SWD practice. (Phifer and Wilhite, 2001)

From the WSF/SCF, B-25 boxes containing waste meeting the waste acceptance criteria for trench disposal (i.e. containing lower levels of radioactivity) are disposed in earthen trenches designated Engineered Trenches. Engineered Trenches are excavated to approximately 22 feet below the ground surface, have surface dimensions of approximately 150 feet by 650 feet (i.e. a surface area of approximately 2.2 acres), have an access ramp at one end, and are lined with gravel to facilitate use of a forklift. The excavated soil is stockpiled for later placement over disposed waste.

Each Engineered Trench is designed to contain approximately 12,000 B-25 boxes. The B-25s are stacked in rows four high (approximately 17 feet high) with a forklift, beginning at the end of the trench opposite the access ramp. As a sufficient number of B-25 rows are placed, stockpiled soil is bulldozed in a 4-foot lift over some of the completed rows so that the covered rows have at least 4 feet of soil over them. This interim soil cover is only applied to that portion of the completed rows that still allows maintenance of a safe distance from the working face (i.e. where new boxes are placed in the stack) within the trench.

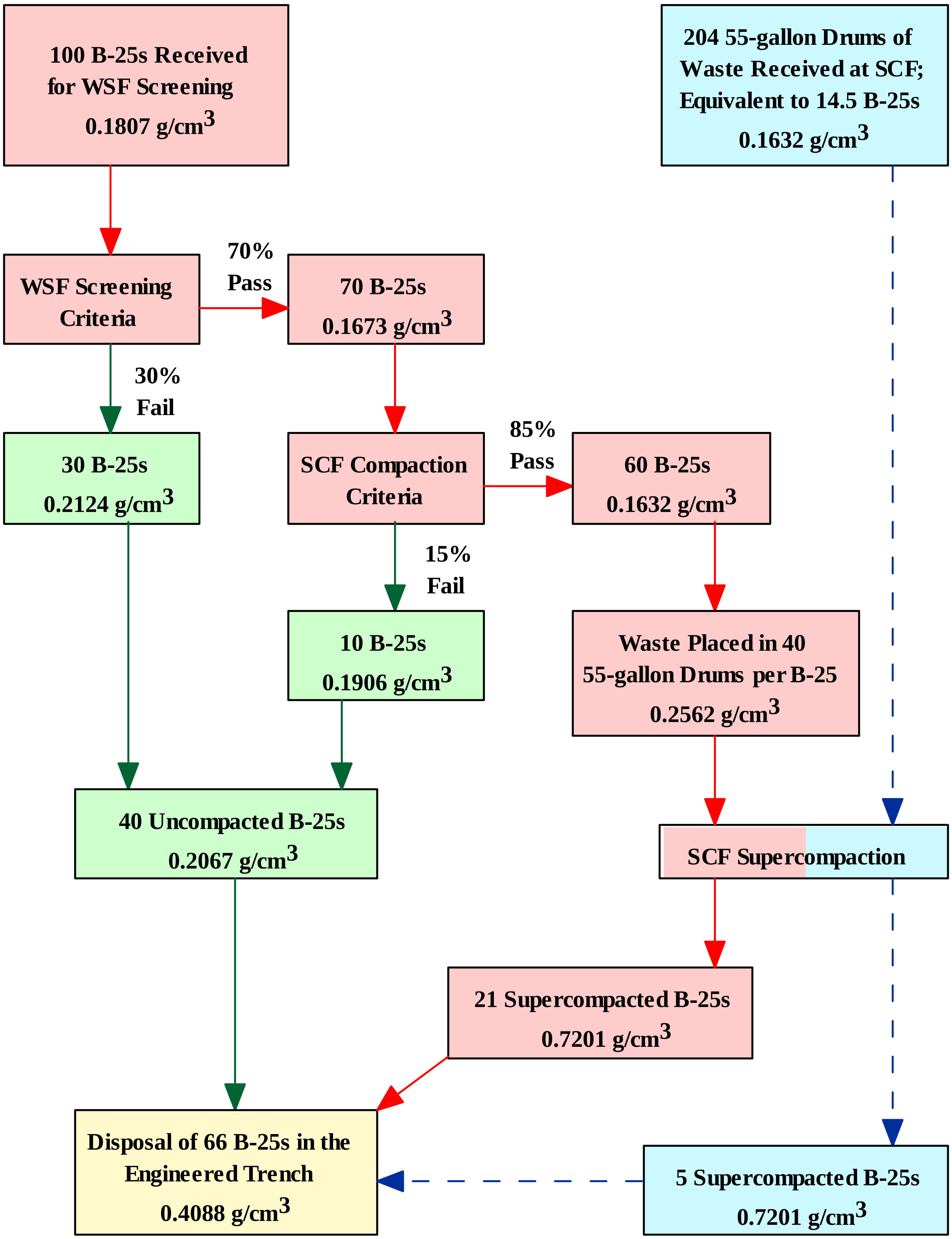

Figure 1. WSF/SCF B-25 Process Flow Diagram from Phifer and Wilhite (2001)

The interim soil cover is graded to provide positive drainage off the trench and away from the working face. Placement of the B-25 boxes continues until the trench is filled with boxes. At that point the minimum 4 feet interim soil cover is placed over the remaining portion of the trench, and the entire area is graded to provide positive drainage off the trench. A final closure cap would subsequently be placed over the Engineered Trench. Subsidence of waste in trenches will be potentially disruptive of the closure cap. (Phifer and Wilhite, 2001)

The SRTC study, documented in Phifer and Wilhite (2001), evaluated the following factors, for six, selected waste/subsidence treatment methods:

- Relative subsidence potential reduction
- Relative closure costs:
  - Relative Engineered Trench Design and Construction Cost
  - Relative waste/subsidence treatment cost (i.e. B-25 box, WSF/SCF, and dynamic compaction costs, as appropriate)
  - Relative closure cap cost
- Relative long-term maintenance cost
  - Relative closure cap subsidence repair costs
  - Relative cumulative operating and maintenance (O&M) cost

The waste/subsidence treatment methods were evaluated on an equivalent waste mass basis to provide a consistent basis for the relative subsidence potential reduction and cost evaluations. The following are the waste/subsidence treatment methods that were evaluated:

- Placement of an interim soil cover over uncompacted B-25 boxes stacked within an Engineered Trench (ISC). This is considered the no action case.
- Placement of an interim soil cover over B-25 boxes processed through the Waste Sort Facility/Super Compactor Facility (WSF/SCF) and stacked within an Engineered Trench (ISC and WSF/SCF)
- Standard dynamic compaction (SDC) of uncompacted B-25 boxes stacked within an Engineered Trench that had received an interim soil cover (ISC and SDC)
- Tertiary dynamic compaction (TDC) of uncompacted B-25 boxes stacked within an Engineered Trench that had received an interim soil cover (ISC and TDC)
- Standard dynamic compaction of stacked B-25 boxes that have been processed through the WSF/SCF within an Engineered Trench that had received an interim soil cover (ISC, SDC, and WSF/SCF)
- Tertiary dynamic compaction of stacked B-25 boxes that have been processed through the WSF/SCF within an Engineered Trench that had received an interim soil cover (ISC, TDC, and WSF/SCF)

The WSF/SCF B-25 process flow diagram (Figure 1) along with the parameters listed in Table 1 provided the basis for determining the costs associated with each of the waste/subsidence treatment methods evaluated in Phifer and Wilhite (2001). Table 2 provides the summary costs and Table 3 provides the summary cost per subsidence reduction and cost per volume of waste received for disposal from the Phifer and Wilhite (2001) study. In summary, of the waste/subsidence treatment methods evaluated, the following cases were eliminated from further consideration on the basis of subsidence potential reduction, cost, and cost per subsidence reduction:

- No action case (ISC alone)
- Waste Sort Facility/Super Compactor Facility only case (ISC and WSF/SCF)
- All cases utilizing standard dynamic compaction (i.e. ISC and SDC and ISC, WSF/SCF, and SDC)

Of the remaining two cases evaluated in Phifer and Wilhite (2001), the following conclusions were drawn on the basis of subsidence potential reduction, cost, cost per subsidence reduction, and cost per volume of waste received for disposal:

- Both tertiary dynamic compaction (ISC and TDC) and the combined use of the WSF/SCF and TDC (ISC, WSF/SCF, and TDC) can reduce the subsidence potential by slightly more than 50%.
- The combined use of WSF/SCF and TDC only results in an additional subsidence potential reduction of 4 percent (seven inches) over that of TDC alone. Therefore, the addition of the WSF/SCF to TDC does not appear to be very effective in providing additional subsidence potential reduction. However, the addition of the WSF/SCF to TDC does result in the utilization of an Engineered Trench with less surface area by a factor of 1.72.
- The TDC alone case has a lower total relative closure cost and a lower relative closure cost per subsidence reduction than the WSF/SCF and TDC case.
- The WSF/SCF and TDC case has a lower long-term maintenance cost and a lower long-term maintenance cost per subsidence reduction than the TDC alone case. The WSF/SCF and TDC case has the lowest subsidence repair cost, since it results in a slightly greater reduction in subsidence potential and utilizes an Engineered Trench with less surface area by a factor of 1.72.
- The case with the lowest total cost, lowest total cost per subsidence reduction, and lowest cost per volume of waste received for disposal depends upon which subsidence repair method is utilized. If the traditional subsidence repair method is utilized, the WSF/SCF and TDC case is lowest, however if the cap replacement method is utilized, the TDC alone case is lowest.

The following are additional conclusions resulting from the Phifer and Wilhite (2001) evaluation:

- The most uncertainty in costs is associated with the long-term subsidence repair costs, which also potentially represent the greatest cost element. The cap replacement subsidence repair method represents the probable lower range of cap subsidence repair costs, whereas the traditional method represents the probable upper range of such costs. The traditional method is the current cap subsidence repair baseline, whereas the cap replacement method is considered innovative and requiring further development prior to implementation. These long-term subsidence repair costs are greatly impacted by the use of B-25 boxes, the waste/subsidence treatment method utilized, and the subsidence repair strategy implemented.
- The B-25 boxes, the WSF/SCF, and subsidence repair cost elements are the ones with the greatest costs and therefore optimization of these elements has the greatest potential to significantly reduce the total costs.
- B-25 box utilization for disposal of relatively low-density waste, which results in large subsidence potentials regardless of the waste/subsidence treatment method evaluated, is directly responsible for high B-25 box, WSF/SCF, and subsidence repair costs. All of the waste/subsidence treatment methods evaluated are simply efforts that try to reduce the subsidence impacts created by the use of B-25 boxes. However none of the waste/subsidence treatments fully eliminates the subsidence impacts of B-25 boxes as evidenced by the subsidence repair costs.
- Significant uncertainty is associated with the timing of B-25 box corrosion and collapse (i.e. time until Engineered Trench stabilization). Within this study this was assumed to occur over a 150-year period for boxes that had been dynamically compacted and over a 300-year period for boxes that had not.

Table 1. Cost Basis Summary – Phifer and Wilhite (2001)

Waste/Subsidence Treatment Method	Relative Subsidence Potential (ft)	Relative Subsidence Potential Reduction (%)	Subsidence Period (years)
Base Subsidence Potential	15.1	0	-
ISC	13.6	9.9	200 to 300
ISC and WSF/SCF	11.7	22.6	200 to 300
ISC and SDC	10.4	31.2	100 to 150
ISC and TDC	7.2	52.4	100 to 150
ISC, WSF/SCF, and SDC	9.2	39.5	100 to 150
ISC, WSF/SCF, and TDC	6.6	56.3	100 to 150

Waste/Subsidence Treatment Method	Waste Mass Equivalent Number of B-25s	Number of Supercompacted B-25s	Engineered Trench Surface Area (acres)	Closure Cap Surface Area (acres)
ISC	20,640	0	3.85	4.28
ISC and WSF/SCF	12,000	4,728	2.24	2.61
ISC and SDC	20,640	0	3.85	4.28
ISC and TDC	20,640	0	3.85	4.28
ISC, WSF/SCF, and SDC	12,000	4,728	2.24	2.61
ISC, WSF/SCF, and TDC	12,000	4,728	2.24	2.61

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 2. Cost Summary – Phifer and Wilhite (2001)

Subsidence Treatment Method	Engineered Trench Cost ($M)	B-25 Box Cost ($M)	WSF/SCF Cost ($M)	Dynamic Compaction Cost ($M)	Closure Cap Cost ($M)	Total Relative Closure Cost ($M)
ISC	3.1	10.8	0.0	0.0	2.4	16.3
ISC and WSF/SCF	1.8	6.3	32.5	0.0	1.5	42.1
ISC and SDC	3.1	10.8	0.0	1.9	2.4	18.2
ISC and TDC	3.1	10.8	0.0	3.6	2.4	19.9
ISC, WSF/SCF, and SDC	1.8	6.3	32.5	1.2	1.5	43.3
ISC, WSF/SCF, and TDC	1.8	6.3	32.5	2.2	1.5	44.2

Subsidence Treatment Method	Traditional Subsidence Repair Cost ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Traditional ($M)	Total Relative Cost - Traditional ($M)
ISC	151.7	3.4	155.1	171.4
ISC and WSF/SCF	75.2	2.9	78.1	120.2
ISC and SDC	116.0	1.7	117.7	135.9
ISC and TDC	80.3	1.7	82.0	101.9
ISC, WSF/SCF, and SDC	59.7	1.5	61.1	104.4
ISC, WSF/SCF, and TDC	41.5	1.5	43.0	87.2

Subsidence Treatment Method	Cap Replacement Subsidence Repair Cost ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Cap Replacement ($M)	Total Relative Cost – Cap Replacement ($M)
ISC	49.8	3.4	53.3	69.6
ISC and WSF/SCF	26.2	2.9	29.1	71.2
ISC and SDC	18.9	1.7	20.7	38.8
ISC and TDC	12.9	1.7	14.7	34.5
ISC, WSF/SCF, and SDC	10.1	1.5	11.6	54.9
ISC, WSF/SCF, and TDC	7.4	1.5	8.8	53.1

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction;
$M = Millions of Dollars

Table 3. Cost per Subsidence Reduction and Cost per Volume of Waste Received for Disposal Summary – Phifer and Wilhite (2001)

Waste/Subsidence Treatment Method	Closure Cost per Subsidence Reduction ($M / %)	Long-term Maintenance Cost – Traditional Method per Subsidence Reduction ($M / %)	Total Cost – Traditional Method per Subsidence Reduction ($M / %)	Total Cost – Traditional Method per Volume of Waste Received ($/m^3)
ISC	1.6	15.7	17.3	3,257
ISC and WSF/SCF	1.9	3.5	5.3	2,284
ISC and SDC	0.6	3.8	4.4	2,582
ISC and TDC	0.4	1.6	1.9	1,936
ISC, WSF/SCF, and SDC	1.1	1.5	2.6	1,983
ISC, WSF/SCF, and TDC	0.8	0.8	1.5	1,657
Waste/Subsidence Treatment Method	**Closure Cost per Subsidence Reduction ($M / %)**	**Long-term Maintenance Cost –Cap Replacement Method per Subsidence Reduction ($M / %)**	**Total Cost – Traditional Method per Subsidence Reduction ($M / %)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/m^3)**
ISC	1.6	5.4	7.0	1,322
ISC and WSF/SCF	1.9	1.3	3.1	1,352
ISC and SDC	0.6	0.7	1.2	738
ISC and TDC	0.4	0.3	0.7	656
ISC, WSF/SCF, and SDC	1.1	0.3	1.4	1,042
ISC, WSF/SCF, and TDC	0.8	0.2	0.9	1,008

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

3.0 INTRODUCTION

Within the previous study (Phifer and Wilhite, 2001), the waste pucks, produced from compaction of low density waste in 55-gallon drums within the Super Compactor Facility, were assumed to be placed in B-25 boxes for disposal in the Engineered Trench. This placement of a round puck in a rectangular box reintroduced some of the subsidence potential that was eliminated by use of the Super Compactor Facility. Therefore , Solid Waste Division requested the Savannah River Technology Center to perform a sensitivity analysis to evaluate the optimal subsidence treatment achievable through use of the Super Compactor Facility.

This additional evaluation assumes that rather than placing the pucks in B-25 boxes for disposal, the pucks are directly disposed (i.e., emplacement without the use of a container) within the Engineered Trench. While this method of disposal represents the optimal subsidence treatment achievable through use of the Super Compactor Facility, Solid Waste Division does not consider it a realistic disposal option. It is not considered a realistic disposal option because supercompaction of compactable low-level waste with 1000 tons of force results in squeezing entrained moisture out of the waste along with potential radioactive contamination. Solid Waste Division has determined that the resulting damp pucks should be containerized to facilitate contamination control and personnel safety.

This study presents the results of this supplemental sensitivity evaluation, which has been conducted consistent with the analysis documented in Phifer and Wilhite (2001). A comparison to the best cases documented in Phifer and Wilhite (2001) is also provided.

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4.0 ANALYSIS

An analysis has been performed to estimate the following factors associated with selected waste/subsidence treatment methods consistent with the analysis documented in Phifer and Wilhite (2001):

- Relative subsidence potential reduction
- Relative closure costs:
  - Relative Engineered Trench Design and Construction Cost
  - Relative waste/subsidence treatment cost (i.e. B-25 box, WSF/SCF, and dynamic compaction costs, as appropriate)
  - Relative closure cap cost
- Relative long-term maintenance cost
  - Relative closure cap subsidence repair costs
  - Relative cumulative operating and maintenance (O&M) cost

The following are the selected waste/subsidence treatment methods, which have been included in this analysis for comparison to the waste/subsidence treatment methods evaluated in Phifer and Wilhite (2001):

- Processing through the Waste Sort Facility/Super Compactor Facility (WSF/SCF) with direct puck disposal (DPD; i.e. pucks are not contained in a B-25 box) on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC) (ISC, WSF/SCF, and DPD)

- Processing through the WSF/SCF with DPD on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC) followed by standard dynamic compaction (SDC) (ISC, WSF/SCF, DPD, and SDC)

- Processing through the WSF/SCF with DPD on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC) followed by tertiary dynamic compaction (TDC) (ISC, WSF/SCF, DPD, and TDC)

This analysis has been performed based upon the following Engineered Trench closure and long-term maintenance strategy for each selected waste/subsidence treatment method evaluated consistent with the analysis documented in Phifer and Wilhite (2001):

- Each of the following disposal, waste/subsidence treatment, and closure activities are assumed to occur immediately after one another with no significant time period between each activity:
  - Waste is processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF), if applicable to the waste/subsidence treatment method under evaluation.
  - The B-25 boxes containing the uncompactable waste are stacked in the Engineered Trench.
  - Supercompacted pucks are placed on top of the stacked B-25 boxes.
  - A minimum four-foot interim soil cover is placed over the pucks and B-25s after the Engineered Trench has been filled.
  - Dynamic compaction is performed, if applicable to the waste/subsidence treatment method under evaluation.
  - A Flexible Membrane Liner / Geosynthetic Clay Liner (FML/GCL) closure cap per Figure 1 is constructed over the Engineered Trench.
- Long-term maintenance begins once the closure cap is completed and continues until the estimated subsidence period has been completed.

All costs presented within this analysis are relative year 2001 costs for comparative purposes only. The costs are not detailed cost estimates. All calculations are provided in Appendix A. The values presented in the body of this report have been rounded off from those presented in Appendix A.

4.1 APPLICABLE DATA AND ASSUMPTIONS FROM PHIFER AND WILHITE (2001)

The following are applicable data and assumptions from Phifer and Wilhite (2001) for an Engineered Trench filled with B-25 Boxes processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF) (i.e., an Engineered Trench containing both supercompacted B-25s and uncompacted B-25s). (See Phifer and Wilhite (2001) for specific references.)

- An Engineered Trench filled with B-25 Boxes processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF) (i.e., an Engineered Trench containing both supercompacted B-25s and uncompacted B-25s) contains a total of 12,000 B-25s. Of these 12,000 B-25s, 4,728 are supercompacted B-25s and 7,272 are uncompacted B-25s.

- Each B-25 box costs $523.
- The cost per supercompacted B-25 is $6,876.
- An Engineered Trench filled with B-25 Boxes processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF) has a surface area of 2.24 acres and requires a closure cap with a surface area of 2.61 acres.
- The average interior volume of a B-25 box is 2,550,000 cm^3 (90 ft3 $\times$ 28,316.85 cm^3/ft^3).
- The exterior dimensions of a B-25 box are as follows: 4.323-foot height, 6.078-foot length, and 3.9115-foot width. The interior dimensions of a B-25 box are as follows: 3.917-foot height, 6.0-foot length, and 3.833-foot width.
- On the average, 40 supercompacted 55-gallon drums (i.e. pucks) are contained in a supercompacted B-25 box.
- It is assumed that the pucks inside supercompacted B-25 are stacked to within 6 inches of the box lid.
- The density of the uncompacted B-25s is 0.2067 g/cm^3.
- It is assumed that the B-25s/waste will eventually compact to an average bulk density of 1.5 g/cm^3.
- The subsidence potential of a stack of four uncompacted B-25 boxes prior to the placement of the interim soil cover is 15.116 feet.
- The subsidence potential due to each B-25 box riser is assumed to be 0.328 feet for a total of 1.312 feet for a stack of four B-25 boxes.
- The lid of uncompacted B-25s is assumed to collapse on average 1.5 feet into the box when the interim soil cover is placed with a bulldozer.
- The maximum subsidence potential reduction that can be produced from the dynamic compaction of a stack of four uncompacted B-25 boxes is 6.427 feet (not considering the treatment surface area).
- Standard dynamic compaction results in the treatment of 50% of the surface area.
- Tertiary dynamic compaction results in the treatment of essentially 100% of the surface area.
- It is assumed that dynamic compaction can eliminate the entire void space due to the risers.
- The subcontractor costs for performance of standard dynamic compaction has been estimated at $100,000 for mobilization/demobilization plus $200,000 per acre.
- The total Standard Dynamic Compaction cost is assumed to be 2 times the subcontractor cost to account for the indirect cost.

- Standard dynamic compaction treats only 50% of the area whereas tertiary dynamic compaction treats 100% of the area. Therefore since standard dynamic compaction has been estimated to cost $200,000 per acre, tertiary dynamic compaction will be assumed to cost $400,000 per acre. Mobilization/ demobilization costs will be assumed to remain at $100,000 for tertiary dynamic compaction.
- The total Tertiary Dynamic Compaction cost is assumed to be 2 times the subcontractor cost to account for the indirect cost.
- An Engineered Trench designed to contain 12,000 B-25 boxes measures 150 feet by 650 feet at the top by 22 feet deep and costs $1,800,000 to design and construct in year 2001 dollars.
- A direct linear relationship is assumed between Engineered Trench Design and Construction cost and the number of B-25s to be disposed.
- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer.
- It is assumed that the cost of the FML/GCL closure caps can be determined from the estimated closure cap construction costs of a 2- and 5-acre cap at $894,156 and $2,206,378, respectively.
- A direct linear relationship is assumed between cost and the acreage of the closure cap.
- For B-25s that are not dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 200 to 300 years after burial.
- For B-25s that are dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 100 to 150 years after burial and dynamic compaction.
- It is assumed that subsidence will occur over the entire surface area of the closure cap, which is directly over the Engineered Trench, over the subsidence period.
- It is assumed that the number of traditional repair events per area will be proportional to the subsidence potential. It is further assumed that every four feet of subsidence will produce a condition requiring repair. Therefore, the number of repair events is assumed to equal the estimated relative subsidence potential divided by four feet. It is assumed that fractions of 4 feet will also require repair due to the extended nature of the subsidence periods.
- A traditional repair cost of $266/ft^2 for a FML/GCL closure cap is.
- The Relative Traditional Cap Subsidence Repair Cost is assumed to equal the following:

$$\text{Repair Cost} = \$266/\ \text{ft}^2 \times \text{Number of Repair Events} \times \text{Surface Area (ft}^2\text{)}$$

- For the closure cap repair method, it is assumed that rather than repairing the closure cap at each subsidence event, as done under the traditional methodology, the following will be performed:
  - Subsidence holes will be filled in with soil to maintain the grade and promote runoff as they occur. The costs associated with this activity are considered to be covered in the cost estimate for the cap replacements, since these costs include site pre-contouring and foundation soil placement costs.
  - The entire cap will be replaced periodically during the duration of subsidence. The frequency of cap replacement will be based upon the relative subsidence potential associated with each case. It is assumed that the cap replacement frequency varies inversely with relative subsidence potential. The cap replacement frequency for the ISC, WSF/SCF and TDC case will be assumed to be 10 years; all other cap replacement frequencies will be determined based upon this case. The old cap will not be removed, but a new cap will be placed directly on top of the old cap.
- It is assumed that Operating and Maintenance (O&M) costs will be incurred until the subsidence period for each case has been completed.
- It is assumed that the Operating and Maintenance costs associated with FML/GCL closure caps can be determined from the 2 and 5 acre cap estimates at $7,200 and $9,700, respectively, as determined from Bhutani, et al., 1993.

4.2 DIRECT PUCK DISPOSAL ASSUMPTIONS

The following are the assumptions made for WSF/SCF Waste/Subsidence Treatment Method cases involving the direct disposal of supercompacted 55-gallon drums (i.e. pucks) without placement in B-25 boxes prior to disposal (that is, the co-disposal of uncompacted B-25s and pucks):

- For the cases involving direct placement of the SCF pucks in the Engineered Trench, it is assumed that the pucks are randomly disposed on top of the stacked uncompacted B-25s.
- It is assumed that the random, direct disposed of pucks will have a similar puck configuration as those pucks contained in B-25 boxes but that the void space will be filled with soil. It is also assumed that the pucks are 2-foot diameter and 0.5- foot thick. It is further assumed that the puck and soil zone has a density of 1.5 g/cm^3 and is therefore not subject to subsidence.
- For the cases involving direct placement of the SCF pucks in the Engineered Trench, it is assumed that all top uncompacted B-25 boxes will collapse 1.5 feet into the box upon placement of the pucks and interim soil cover.
- It is assumed that the WSF/SCF cost will not substantially change by not using B-25 boxes to place the pucks in after super compaction.

- It is assumed that the height of disposal remains the same (i.e. total waste and container thickness of approximately 17.3 feet), and therefore there is a direct, one to one relationship between volume and area reductions.
- It is assumed that mass equivalency is maintained by evaluating direct puck disposal in terms of an equivalent number of pucks.

4.3 EQUIVALENCE TO PREVIOUS STUDY

In Phifer and Wilhite (2001) six waste/subsidence treatment methods were evaluated on an equivalent waste mass basis in order to provide a consistent basis for the relative subsidence potential reduction and cost evaluations. In this study, three waste/subsidence treatment methods are evaluated which directly correspond to three of the waste/subsidence treatment methods evaluated in Phifer and Wilhite (2001). The three Phifer and Wilhite (2001) waste/subsidence treatment methods, which correspond to the methods evaluated in this report, are as follows:

- Placement of an interim soil cover over B-25 boxes processed through the Waste Sort Facility/Super Compactor Facility (WSF/SCF) and stacked within an Engineered Trench (ISC and WSF/SCF)
- Standard dynamic compaction of stacked B-25 boxes that have been processed through the WSF/SCF within an Engineered Trench that had received an interim soil cover (ISC, SDC, and WSF/SCF)
- Tertiary dynamic compaction of stacked B-25 boxes that have been processed through the WSF/SCF within an Engineered Trench that had received an interim soil cover (ISC, TDC, and WSF/SCF)

The three waste/subsidence treatment methods evaluated in this study are nearly identical to those above from Phifer and Wilhite (2001). All include processing through the WSF/SCF and may or may not include dynamic compaction. However, rather than placing the supercompacted pucks in B-25 boxes prior to disposal in the Engineered Trench as assumed in Phifer and Wilhite (2001), the pucks are directly disposed in the Engineered Trench, without being contained in B-25 boxes [direct puck disposal (DPD)].

Within Phifer and Wilhite (2001) all cases involving the use of WSF/SCF, consisted of the disposal of 12,000 B-25 boxes of which 4,728 are supercompacted B-25s and 7,272 are uncompacted B-25s. Within this study all cases involve the disposal of 7,272 uncompacted B-25s and a number of supercompacted pucks equivalent to 4,728 supercompacted B-25 boxes. In order to determine the equivalence between this study and the previous Phifer and Wilhite (2001) study, the following assumptions were made:

- It is assumed that the height of disposal remains the same as a stack of four B-25 boxes (i.e. total waste and container thickness of approximately 17.3 feet), and therefore there is a direct, one to one correspondence between volume and area reductions.

- An Engineered Trench filled with B-25 Boxes processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF) has a surface area of 2.24 acres and requires a closure cap with a surface area of 2.61 acres (Phifer and Wilhite, 2001).
- The exterior dimensions of a B-25 box are as follows: 4.323-foot height, 6.078-foot length, and 3.9115-foot width. The interior dimensions of a B-25 box are as follows: 3.917-foot height, 6.0-foot length, and 3.833-foot width.
- It is assumed that the pucks inside supercompacted B-25s are stacked to within 6 inches (0.5 feet) of the box lid (Phifer and Wilhite, 2001).
- It is assumed that the pucks are 2-foot diameter and 0.5- foot thick..

Based upon the above assumptions, equivalent numbers of B-25 boxes and pucks and equivalent volumes and areas have been determined in order to maintain the cases presented in this study on an equivalent waste mass basis to those in Phifer and Wilhite (2001). This provides a consistent basis for the relative subsidence potential reduction and cost evaluations between this study and Phifer and Wilhite (2001), so that direct comparisons may be made. Table 4 provides the calculated values of equivalence for necessary parameters to this study. Appendix A provides the detailed assumptions and calculations for all values presented in the study.

Table 4. Equivalence to Previous Study (Phifer and Wilhite, 2001) Summary

Waste/Subsidence Treatment Method	Number of Uncompacted B-25 Boxes[1]	Equivalent Number of Supercompacted B-25s	Equivalent number of pucks	Puck Volume Equivalent Number of B-25 Boxes
ISC, WSF/SCF, and DPD	7,272	4,728	189,120	3,782
ISC, WSF/SCF, DPD, and SDC	7,272	4,728	189,120	3,782
ISC, WSF/SCF, DPD, and TDC	7,272	4,728	189,120	3,782
Waste/Subsidence Treatment Method	**Puck Volume Equivalent Total Number of B-25 Boxes**	**Engineered Trench Surface Area (acres)**	**Closure Cap Surface Area (acres)**	**Subsidence Period (years)**
ISC, WSF/SCF, and DPD	11,054	2.06	2.40	200 to 300
ISC, WSF/SCF, DPD, and SDC	11,054	2.06	2.40	100 to 150
ISC, WSF/SCF, DPD, and TDC	11,054	2.06	2.40	100 to 150

[1] This is also the number of B-25 boxes used and disposed.

4.4 RELATIVE SUBSIDENCE POTENTIAL AND SUBSIDENCE POTENTIAL REDUCTION

The relative subsidence potential and the relative subsidence potential reduction have been estimated for each of the waste/subsidence treatment methods. As in Phifer and Wilhite (2001) the subsidence potential, resulting from each of the waste/subsidence treatment methods, is based upon the assumption that the waste will eventually attain a bulk density of 1.5 g/cm^3. A bulk density of 1.5 g/cm^3 is equivalent to a typical bulk density for soil and for typical sanitary landfill waste. Within Phifer and Wilhite (2001), the base relative subsidence potential, against which all of the waste/subsidence treatment methods have been evaluated, was estimated at 15.1 feet for a stack of four uncompacted B-25 boxes prior to the placement of the interim soil cover. See Appendix A for the detailed assumptions and calculations. See Table 5 for the summary results, which are based upon the following primary assumptions:

- It is assumed that the puck and soil zone has a density of 1.5 g/cm^3 and is therefore not subject to subsidence.
- The density of waste in the uncompacted B-25s is 0.2067 g/cm^3 (Phifer and Wilhite, 2001).
- The maximum subsidence potential reduction that can be produced from the dynamic compaction of a stack of four uncompacted B-25 boxes is 6.427 feet (not considering the treatment surface area) (Phifer and Wilhite, 2001).
- Standard dynamic compaction results in the treatment of 50% of the surface area. Tertiary dynamic compaction results in the treatment of essentially 100% of the surface area. (Phifer and Wilhite, 2001)

As seen in Table 5, an Engineered Trench containing uncompacted B-25s with direct disposed pucks on top that is then covered with an interim soil cover (ISC, WSF/SCF, and DPD) results in a remaining 9.75-foot relative subsidence potential and produces a 35.5 percent subsidence potential reduction over the base subsidence potential. Standard dynamic compaction of such an Engineered trench (ISC, WSF/SCF, DPD, and SDC) results in a remaining 7.64-foot relative subsidence potential and a 49.5 percent subsidence potential reduction. Tertiary dynamic compaction (ISC, WSF/SCF, DPD, and TDC) results in a remaining 5.52-foot relative subsidence potential and a 63.5 percent subsidence potential reduction. Of the three cases evaluated within this study ISC, WSF/SCF, DPD, and TDC produces the most subsidence potential reduction.

As noted in Phifer and Wilhite (2001), these relative subsidence potential estimates do not directly take into account the subsidence potential due to degradation of the waste materials themselves other than for B-25 box corrosion. It should also be noted that the dynamic compaction performed to date at SRS has not been optimized to obtain the most compaction reasonably achievable. Such optimization could potentially produce additional subsidence potential reduction over that estimated. Such optimization would need to be based upon both modeling and field studies, and may of course cost more than the standard and tertiary dynamic compaction methodologies outlined above. Dynamic compaction optimization could be realized through both the modification of the dynamic compaction methodology and the timing of dynamic compaction relative to the corrosion and subsequent strength reduction of B-25 boxes.

Table 5. Relative Subsidence Potential and Relative Subsidence Potential Reduction

Subsidence Treatment Method	Relative Subsidence Potential (ft)	Relative Subsidence Potential Reduction (%)
Base Subsidence Potential [1]	15.1	0.0
ISC, WSF/SCF, and DPD	9.75	35.5
ISC, WSF/SCF, DPD, and SDC	7.64	49.5
ISC, WSF/SCF, DPD, and TDC	5.52	63.5

[1] Subsidence Potential of a stack of four uncompacted B-25 boxes prior to the placement of the interim soil cover
ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.5 RELATIVE ENGINEERED TRENCH DESIGN AND CONSTRUCTION COST

The relative cost of Engineered Trench design and construction has been estimated for each waste/subsidence treatment method. See Table 6 for the summary results, which are based upon the following primary assumptions:

- Cost of Engineered Trench design and construction for one 12,000 B-25 Box Engineered Trench is $1,800,000 (Phifer and Wilhite, 2001).
- A direct linear relationship is assumed between the design and construction cost and the equivalent number of B-25s to be disposed for each case under consideration (Phifer and Wilhite, 2001).

As shown in Table 6, all cases result in an estimated Engineered Trench design and construction cost of $1.7 M.

Table 6. Relative Engineered Trench Design and Construction Cost

Waste/Subsidence Treatment Method	Volume Equivalent Number of B-25 Boxes Disposed	Relative Engineered Trench Design and Construction Cost ($M)
ISC, WSF/SCF, and DPD	11,054	1.7
ISC, WSF/SCF, DPD, and SDC	11,054	1.7
ISC, WSF/SCF, DPD, and TDC	11,054	1.7

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.6 RELATIVE WASTE/SUBSIDENCE TREATMENT METHODS COST

The relative cost of waste/subsidence treatment has been estimated for each waste/subsidence treatment method. These costs include the costs of B-25 boxes, the WSF/SCF, and dynamic compaction as appropriate. See Table 7 for the summary results, which are based upon the following primary assumptions:

- The cost of B-25 boxes is not included in the WSF/SCF costs; however the cost of 55-gallon drums is included. Each B-25 box costs $523.
- It is assumed that the WSF/SCF cost will not substantially change by not using B-25 boxes to place the pucks in after super compaction. WSF/SCF cost is equivalent to $6,876 per supercompacted B-25 box (Phifer and Wilhite, 2001).
- Based upon past SRS experience the subcontractor costs for performance of standard dynamic compaction has been estimated at $100,000 for mobilization/ demobilization plus $200,000 per acre.
- Standard dynamic compaction treats only 50% of the area whereas tertiary dynamic compaction treats 100% of the area. Therefore, since standard dynamic compaction has been estimated to cost $200,000 per acre, tertiary dynamic compaction will be assumed to cost $400,000 per acre. Mobilization/ demobilization costs will be assumed to remain at $100,000 for tertiary dynamic compaction.
- The total Standard and Tertiary Dynamic Compaction cost is assumed to be 2 times the subcontractor cost to account for the indirect cost (Phifer and Wilhite, 2001).

As shown in Table 7, the B-25 box and WSF/SCF cost are identical for all three cases. The only difference in costs is associated with whether or not and what type of dynamic compaction is performed. The relative waste/subsidence treatment costs span a narrow range from $36.3 M to $38.3 M for all cases.

Table 7. Relative Waste/Subsidence Treatment Cost

Waste/Subsidence Treatment	Number of B-25s Disposed	Equivalent Number of Supercompacted B-25s	Engineered Trench Surface Area (acres)
ISC, WSF/SCF, and DPD	7,272	4,728	2.06
ISC, WSF/SCF, DPD, and SDC	7,272	4,728	2.06
ISC, WSF/SCF, DPD, and TDC	7,272	4,728	2.06

Waste/Subsidence Treatment	B-25 Box Cost ($M)	WSF/SCF Cost ($M)	Dynamic Compaction Cost ($M)	Relative Waste/Subsidence Treatment Cost ($M)
ISC, WSF/SCF, and DPD	3.8	32.5	0	36.3
ISC, WSF/SCF, DPD, and SDC	3.8	32.5	1.1	37.4
ISC, WSF/SCF, DPD, and TDC	3.8	32.5	2.0	38.3

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.7 RELATIVE CLOSURE CAP COST

The relative cost of a closure cap has been estimated for each waste/subsidence treatment method. See Table 8 for the summary results, which are based upon the following primary assumptions:

- It is assumed that the closure cap over the Engineered Trench will consist of a high density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer (Phifer and Wilhite, 2001).
- It is assumed that the cost of the FML/GCL closure caps can be determined from the estimated closure cap construction costs of a 2 and 5 acre cap at $894,156 and $2,206,378 as determined from a 1993 study (Phifer and Wilhite, 2001).
- A direct linear relationship is assumed between cost and the acreage of the closure cap (Phifer and Wilhite, 2001).

As can seen from Table 8, a 2.40-acre closure cap at a relative cost of $1.4 M is required for all cases.

Table 8. Relative Closure Cap Cost

Waste/Subsidence Treatment	Engineered Trench Surface Area (acres)	Closure Cap Surface Area (acres)	Relative FML/GCL Closure Cap Cost ($M)
ISC, WSF/SCF, and DPD	2.06	2.40	1.4
ISC, WSF/SCF, DPD, and SDC	2.06	2.40	1.4
ISC, WSF/SCF, DPD, and TDC	2.06	2.40	1.4

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.8 TOTAL RELATIVE CLOSURE COST SUMMARY

Table 9 provides the total relative closure costs, which consist of the following as stated previously:

- Relative Engineered Trench Design and Construction Cost
- Relative waste/subsidence treatment cost (i.e. B-25 box, WSF/SCF, and dynamic compaction costs)
- Relative closure cap cost

As shown in Table 9, the total relative closure costs, which are the short-term costs, span a narrow range from $39.3 M to $41.3 M for all cases.

Table 9. Total Relative Closure Costs

Waste/Subsidence Treatment Method	Relative Engineered Trench Design and Construction Cost ($M)	Relative Waste/ Subsidence Treatment Cost ($M)	Relative FML/GCL Closure Cap Cost ($M)	Total Relative Closure Cost ($M)
ISC, WSF/SCF, and DPD	1.7	36.3	1.4	39.3
ISC, WSF/SCF, DPD, and SDC	1.7	37.4	1.4	40.4
ISC, WSF/SCF, DPD, and TDC	1.7	38.3	1.4	41.3

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.9 RELATIVE CLOSURE CAP SUBSIDENCE REPAIR COST

As in Phifer and Wilhite (2001), the following two methods of closure cap subsidence repair have been evaluated to provide a range of anticipated relative closure cap subsidence repair costs:

- The traditional method consists of closure cap repair immediately after each subsidence event occurs, during the estimated duration of subsidence. This method represents the upper range of possible closure cap, subsidence repair cost.
- The cap replacement method consists of the following two actions during the estimated duration of subsidence. This method represents the lower range of possible closure cap, subsidence repair cost.
    - Subsidence holes will be filled in with soil to maintain the grade and promote runoff soon after each subsidence event occurs.
    - The entire cap will be replaced periodically during the duration of subsidence at a frequency based upon the relative subsidence potential associated with each case. The old cap will not be removed, but a new cap will be placed directly on top of the old liner after removing overlying materials.

Also as in Phifer and Wilhite (2001), the period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 200 to 300 years after burial for B-25s that are not dynamically compacted. It has been assumed to be from 100 to 150 years after burial and dynamic compaction for B-25s that are dynamically compacted.

Depending upon the method of closure cap subsidence repair utilized, the costs are also assumed to be dependent upon the relative subsidence potential and either the Engineered Trench surface area or the closure cap surface area (Phifer and Wilhite, 2001). Table 10 provides all of these parameters which are assumed to impact the long-term subsidence of the closure cap and subsequently the closure cap subsidence repair costs.

Table 10. Long-term Subsidence Parameters

Waste/Subsidence Treatment	Subsidence Period (years)	Relative Subsidence Potential (ft)	Engineered Trench Surface Area (ft^2)	Closure Cap Surface Area (acres)
ISC, WSF/SCF, and DPD	200 to 300	9.75	89,734	2.40
ISC, WSF/SCF, DPD, and SDC	100 to 150	7.64	89,734	2.40
ISC, WSF/SCF, DPD, and TDC	100 to 150	5.52	89,734	2.40

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility; DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

4.9.1 Relative Closure Cap Subsidence Repair Cost – Traditional Method

The traditional method of closure cap subsidence repair is based on the typical requirements associated with RCRA/CERCLA closure caps, and it is therefore considered the current closure cap repair baseline. This method represents the upper range of possible closure cap, subsidence repair cost. This method consists of closure cap repair soon after each subsidence event occurs, during the anticipated duration of subsidence. The relative cost of a closure cap subsidence repair utilizing the traditional method has been estimated for each waste/subsidence treatment method. These estimated costs are assumed to represent the upper range of probable closure cap, subsidence repair costs.

To provide a consistent basis for the relative cost evaluations, all cost evaluations have been performed on an equivalent waste mass basis. (Phifer and Wilhite, 2001) See Table 11 for the summary results, which are based upon the following:

- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer (Phifer and Wilhite, 2001).
- It is assumed that subsidence will occur over the entire surface area of the closure cap, which is directly over the Engineered Trench, over the subsidence period.
- It is assumed that the number of traditional repair events per area will be proportional to the subsidence potential. It is further assumed that every four feet of subsidence will produce a condition, requiring repair. Therefore, the number of repair events is assumed to equal the estimated relative subsidence potential divided by four feet. It is assumed that fractions of 4 feet will also require repair due to the extended nature of the subsidence periods (Phifer and Wilhite, 2001).
- A traditional repair cost of $266/ft^2 for a FML/GCL closure cap is assumed (Phifer and Wilhite, 2001).

As seen in Table 11, an Engineered Trench containing uncompacted B-25s with direct disposed pucks on top that is then covered with an interim soil cover (ISC, WSF/SCF, and DPD) results in a cost of $58.2 M to repair subsidence by the traditional method. Standard dynamic compaction of such an Engineered trench (ISC, WSF/SCF, DPD, and SDC) results in a cost of $45.6 M to repair subsidence by the traditional method, and tertiary dynamic compaction (ISC, WSF/SCF, DPD, and TDC) results in a cost of $32.9 M. The closure cap subsidence repair costs are long-term costs. Of the three cases evaluated within this study, ISC, WSF/SCF, DPD, and TDC results in the least long-term closure cap repair cost. This case has the least long-term closure cap repair cost, since it results in the smallest subsidence potential and lowest resulting number of repair events.

Table 11. Relative Closure Cap Subsidence Repair Cost – Traditional Method

Waste/Subsidence Treatment	Engineered Trench Surface Area (ft^2)	Number of Repair Events	Relative Closure Cap Subsidence Repair Cost - Traditional Method ($M)
ISC, WSF/SCF, and DPD	89,734	2.44	58.2
ISC, WSF/SCF, DPD, and SDC	89,734	1.91	45.6
ISC, WSF/SCF, DPD, and TDC	89,734	1.38	32.9

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.9.2 Relative Closure Cap Subsidence Repair Cost – Cap Replacement Method

The cap replacement method consists of filling subsidence holes with soil to maintain the grade and promote runoff as they occur and of replacing the entire closure cap periodically during the duration of subsidence at a frequency based upon the relative subsidence potential associated with each case. The old cap will not be removed, but a new cap will be placed directly on top of the old liner after removing overlying materials. This method of cap repair is not standard practice and is therefore considered innovative and requiring further development prior to implementation. This method represents the lower range of possible closure cap, subsidence repair cost. The relative cost of closure cap subsidence repair utilizing the cap replacement method has been estimated for each waste/subsidence treatment method. (Phifer and Wilhite, 2001) See Table 12 for the summary results, which are based upon the following primary assumptions:

- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer (Phifer and Wilhite, 2001).
- It is assumed that subsidence will occur over the entire surface area of the closure cap, which is directly over the Engineered Trench, over the subsidence period (Phifer and Wilhite, 2001).
- It is assumed that rather than repairing the closure cap at each subsidence event, as done under the traditional methodology, the following will be performed (Phifer and Wilhite, 2001):

- Subsidence holes will be filled in with soil to maintain the grade and promote runoff as they occur. The costs associated with this activity are considered to be covered in the cost estimate for the cap replacements, since these costs include site pre-contouring and foundation soil placement costs.
- The entire cap will be replaced periodically during the duration of subsidence. The frequency of cap replacement will be based upon the relative subsidence potential associated with each case. It is assumed that the cap replacement frequency varies inversely with relative subsidence potential. The cap replacement frequency for the Phifer and Wilhite (2001) ISC, WSF/SCF and TDC case will be assumed to be 10 years; all other cap replacement frequencies will be determined based upon this case. The old cap will not be removed, but a new cap will be placed directly on top of the old cap.

As seen in Table 12, an Engineered Trench containing uncompacted B-25s with direct disposed pucks on top that is then covered with an interim soil cover (ISC, WSF/SCF, and DPD) results in a cost of $19.9 M to repair subsidence by the cap replacement method. Standard dynamic compaction of such an Engineered trench (ISC, WSF/SCF, DPD, and SDC) results in a cost of $7.9 M to repair subsidence by the cap replacement method, and tertiary dynamic compaction (ISC, WSF/SCF, DPD, and TDC) results in a cost of $5.7 M.

The closure cap subsidence repair costs are long-term costs. Of the three cases evaluated within this study, ISC, WSF/SCF, DPD, and TDC results in the least long-term closure cap repair cost. This case has the least long-term closure cap repair cost, since it results in the smallest subsidence potential and lowest resulting number of replacement caps.

Table 12. Relative Closure Cap Subsidence Repair Cost – Cap Replacement Method

Waste/ Subsidence Treatment	Duration of Subsidence (years)	Cap Replacement Frequency (years)	Number of Replacement Caps	Cost per Replacement Cap (M)	Relative Cap Subsidence Repair Cost - Cap Replacement Method (M)
ISC, WSF/SCF, and DPD	100	6.8	14.7	1.4	19.9
ISC, WSF/SCF, DPD, and SDC	50	8.6	5.8	1.4	7.9
ISC, WSF/SCF, DPD, and TDC	50	12.0	4.2	1.4	5.7

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.10 RELATIVE CUMULATIVE OPERATING AND MAINTENANCE COST

The relative cumulative operating and maintenance (O&M) cost has been estimated for each waste/subsidence treatment method. See Table 13 for the summary results, which are based upon the following primary assumptions:

- It is assumed that Operating and Maintenance (O&M) costs will be incurred until the subsidence period for each case has been completed (Phifer and Wilhite, 2001).
- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer (Phifer and Wilhite, 2001).
- It is assumed that the Operating and Maintenance costs associated with FML/GCL closure caps can be determined from the 2- and 5-acre cap estimates at $7,200 and $9,700, respectively, as determined from Bhutani, et al., 1993 (Phifer and Wilhite, 2001).
- A direct linear relationship is assumed between cost and the acreage of the closure cap (Phifer and Wilhite, 2001).

As seen in Table 13 the relative cumulative O&M costs for the cases involving dynamic compaction (ISC, WSF/SCF, DPD, and SDC and ISC, WSF/SCF, DPD, and TDC) are $1.4 M, whereas the cost for the case that does not involve dynamic compaction (ISC, WSF/SCF, and DPD) is $2.9 M. This difference is due to the assumption that dynamic compaction reduces the total subsidence period and thus reducing the relative cumulative O&M costs.

Table 13. Relative Cumulative O&M Cost

Waste/Subsidence Treatment	Closure Cap Surface Area (acres)	Yearly O&M Cost ($/year)	Subsidence Period (years)	Relative Cumulative O&M Cost [1] ($M)
ISC, WSF/SCF, and DPD	2.40	9,543	300	2.9
ISC, WSF/SCF, DPD, and SDC	2.40	9,543	150	1.4
ISC, WSF/SCF, DPD, and TDC	2.40	9,543	150	1.4

[1] Relative Cumulative O&M Cost = Yearly O&M Cost ($/year) × Subsidence Period (years)
ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction;
TDC = Tertiary Dynamic Compaction

4.11 TOTAL RELATIVE LONG-TERM MAINTENANCE COST

Table 14 provides the estimated total relative long-term maintenance costs, which consist of the following as stated previously:

- Relative closure cap subsidence repair cost (traditional or cap replacement methods)
- Relative cumulative operating and maintenance (O&M) cost

As seen in Table 14, an Engineered Trench containing uncompacted B-25s with direct disposed pucks on top that is then covered with an interim soil cover (ISC, WSF/SCF, and DPD) results in a relative long-term maintenance cost of $61.1 M with the traditional method of subsidence repair. Standard dynamic compaction of such an Engineered trench (ISC, WSF/SCF, DPD, and SDC) results in a relative long-term maintenance cost of $47.0 M with the traditional method of subsidence repair, and tertiary dynamic compaction (ISC, WSF/SCF, DPD, and TDC) results in a cost of $34.4 M. Similarly ISC, WSF/SCF, and DPD results in a relative long-term maintenance cost of $22.8 M with the cap replacement method of subsidence repair. ISC, WSF/SCF, DPD, and SDC results in a cost of $9.3 M with the cap replacement method of subsidence repair, and ISC, WSF/SCF, DPD, and TDC results in a cost of $7.1 M.

Of the three cases evaluated within this study, the ISC, WSF/SCF, DPD, and TDC results in the least long-term maintenance cost. This is due to its having the least subsidence potential and the least subsidence period. The use of the cap replacement method of subsidence repair also results in lower long-term maintenance costs. However, this method of cap repair is not standard practice and is therefore considered innovative and requiring further development prior to implementation.

4.12 RELATIVE COST PER SUBSIDENCE POTENTIAL

To provide an evaluation cost-effectiveness of each waste/subsidence treatment method relative to the subsidence potential reduction it produces, the following costs per percent relative subsidence potential reduction has been calculated for each method:

- Total Relative Closure Cost per Relative Subsidence Potential Reduction
- Total Relative Closure Cost per Relative Subsidence Potential Reduction
- Total Relative Cost per Relative Subsidence Potential Reduction

This ratio essentially provides a way to measure “your bang for your buck” relative to subsidence potential reduction. Table 15, Table 16, and Table 17 provide the costs per percent, relative subsidence potential reduction and Appendix A provides the detailed calculations. The Table 15, 16, and 17 costs per percent, relative subsidence potential reduction, values demonstrate that the ISC, WSF/SCF, DPD, and TDC waste/subsidence treatment method results in the most “bang for your buck” of the cases evaluated in this study.

ISC, WSF/SCF, DPD, and TDC involves the placement of uncompacted B-25s with direct disposed pucks on top in an Engineered Trench that is then covered with an interim soil cover and receives tertiary dynamic compaction. The use of the cap replacement method of subsidence repair also results in more “bang for your buck” than the use of the traditional method. However, this method of cap repair is not standard practice and is therefore considered innovative and requiring further development prior to implementation.

Table 14. Total Relative Long-term Maintenance Cost

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Traditional Method ($M)	Relative Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Traditional Method ($M)
ISC, WSF/SCF, and DPD	58.2	2.9	61.1
ISC, WSF/SCF, DPD, and SDC	45.6	1.4	47.0
ISC, WSF/SCF, DPD, and TDC	32.9	1.4	34.4
Waste/Subsidence Treatment Method	**Relative Cap Subsidence Repair Cost - Cap Replacement Method (M)**	**Relative Cumulative O&M Cost ($M)**	**Total Relative Long-term Maintenance Cost – Cap Replacement Method ($M)**
ISC, WSF/SCF, and DPD	19.9	2.9	22.8
ISC, WSF/SCF, DPD, and SDC	7.9	1.4	9.3
ISC, WSF/SCF, DPD, and TDC	5.7	1.4	7.1

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 15. Total Relative Closure Cost per Relative Subsidence Potential Reduction

Waste/Subsidence Treatment Method	Total Relative Closure Cost ($M)	Relative Subsidence Potential Reduction (%)	Closure Cost per Subsidence Potential Reduction (M / %)
ISC, WSF/SCF, and DPD	39.3	35.5	1.11
ISC, WSF/SCF, DPD, and SDC	40.4	49.5	0.82
ISC, WSF/SCF, DPD, and TDC	41.3	63.5	0.65

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 16. Total Relative Long-term Maintenance Cost per Relative Subsidence Potential Reduction

Waste/Subsidence Treatment Method	Total Relative Long-term Maintenance Cost – Traditional Method ($M)	Relative Subsidence Potential Reduction (%)	Long-term Maintenance Cost – Traditional Method per Subsidence Potential Reduction (M / %)
ISC, WSF/SCF, and DPD	61.1	35.5	1.72
ISC, WSF/SCF, DPD, and SDC	47.0	49.5	0.95
ISC, WSF/SCF, DPD, and TDC	34.4	63.5	0.54
Waste/Subsidence Treatment Method	**Total Relative Long-term Maintenance Cost – Cap Replacement Method (M)**	**Relative Subsidence Potential Reduction (%)**	**Long-term Maintenance Cost – Cap Replacement Method per Subsidence Potential Reduction ($M / %)**
ISC, WSF/SCF, and DPD	22.8	35.5	0.64
ISC, WSF/SCF, DPD, and SDC	9.3	49.5	0.19
ISC, WSF/SCF, DPD, and TDC	7.1	63.5	0.11

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 17. Total Relative Cost per Relative Subsidence Potential Reduction

Waste/Subsidence Treatment Method	Total Relative Cost ($M)	Relative Subsidence Potential Reduction (%)	Total Cost per Subsidence Potential Reduction ($M / %)
ISC, WSF/SCF, and DPD	100.4	35.5	2.83
ISC, WSF/SCF, DPD, and SDC	87.5	49.5	1.77
ISC, WSF/SCF, DPD, and TDC	75.7	63.5	1.19
Waste/Subsidence Treatment Method	**Total Relative Cost – Cap Replacement Method ($M)**	**Relative Subsidence Potential Reduction (%)**	**Total Cost per Subsidence Potential Reduction–Cap Replacement Method [1] ($M / %)**
ISC, WSF/SCF, and DPD	62.1	35.5	1.75
ISC, WSF/SCF, DPD, and SDC	49.7	49.5	1.00
ISC, WSF/SCF, DPD, and TDC	48.5	63.5	0.76

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

4.13 RELATIVE TOTAL COST PER VOLUME OF WASTE RECEIVED

As an additional means of evaluating the various cases, the relative total cost per volume of waste received for disposal has been determined. See Appendix A for the detailed calculations and Table 18 for the summary results. Table 18 demonstrates that the ISC, WSF/SCF, DPD, and TDC waste/subsidence treatment method results in the least total cost per volume of waste received of the cases evaluated in this study. ISC, WSF/SCF, DPD, and TDC involves the placement of uncompacted B-25s with direct disposed pucks on top in an Engineered Trench that is then covered with an interim soil cover and receives tertiary dynamic compaction. The use of the cap replacement method of subsidence repair also results in a lower cost per volume of waste received than the use of the traditional method. However this method of cap repair is not standard practice and is therefore considered innovative and requiring further development prior to implementation.

Table 18. Relative Total Cost per Volume of Waste Received

Waste/Subsidence Treatment Method	Total Cost – Traditional Method ($)	Initial Volume (m^3)	Total Cost – Traditional Method per Volume of Waste Received ($/$m^3$)
ISC, WSF/SCF, and DPD	100,429,299	52,632	1,908
ISC, WSF/SCF, DPD, and SDC	87,466,075	52,632	1,662
ISC, WSF/SCF, DPD, and TDC	75,715,761	52,632	1,439
Waste/Subsidence Treatment Method	**Total Cost – Cap Replacement Method ($)**	**Initial Volume (m^3)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/$m^3$)**
ISC, WSF/SCF, and DPD	62,097,436	52,632	1,180
ISC, WSF/SCF, DPD, and SDC	49,731,107	52,632	945
ISC, WSF/SCF, DPD, and TDC	48,464,516	52,632	921

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

4.14 ANALYSIS SUMMARY

Table 19, Table 20, and Table 21 provide an analysis summary. As shown in Table 1, ISC, WSF/SCF, DPD, and TDC results in the least relative subsidence potential and the greatest relative subsidence potential reduction of the cases evaluated within this study. ISC, WSF/SCF, DPD, and TDC involves the placement of uncompacted B-25s with direct disposed pucks on top in an Engineered Trench that is then covered with an interim soil cover and receives tertiary dynamic compaction.

Table 19. Relative Subsidence Potential and Subsidence Potential Reduction Summary

Subsidence Treatment Method	Relative Subsidence Potential (ft)	Relative Subsidence Potential Reduction (%)
ISC, WSF/SCF, and DPD	9.75	35.5
ISC, WSF/SCF, DPD, and SDC	7.64	49.5
ISC, WSF/SCF, DPD, and TDC	5.52	63.5

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

As shown in Table 20, the ISC, WSF/SCF, DPD, and TDC case has the greatest relative closure cost (short-term cost) at $41.3 M of the cases evaluated in this study, however this is only $2 M more than the case with the lowest short-term cost (ISC, WSF/SCF, and DPD). The ISC, WSF/SCF, DPD, and TDC case has both the least relative long-term maintenance cost (long-term cost) and the least total cost of the cases evaluated in this study. Additionally, the use of the cap replacement method of subsidence repair also results in lower costs than the use of the traditional method. However this method of cap repair is not standard practice and is therefore considered innovative and requiring further development prior to implementation.

As shown in Table 21, ISC, WSF/SCF, DPD, and TDC has both the least cost per subsidence reduction and the least cost per volume of waste received of the cases evaluated within this study. Again, the use of the cap replacement method of subsidence repair also results in lower costs per subsidence reduction and the lower costs per volume of waste received.

Based upon the above summary information, the ISC, WSF/SCF, DPD, and TDC case overall was determined to be the most technically effective and cost efficient of the cases evaluated in this study. It also represents the best in terms of both subsidence potential reduction and total cost that can possibly be achieved with supercompaction (WSF/SCF). Therefore, only ISC, WSF/SCF, DPD, and TDC of the cases evaluated within this study will be compared to the best cases evaluated within Phifer and Wilhite (2001) within the Summary and Conclusions section (Section 5.0).

Table 20. Relative Cost Summary

Waste/ Subsidence Treatment Method	Engineered Trench Cost (M)	B-25 Box Cost (M)	WSF/SCF Cost (M)	Dynamic Compaction Cost (M)	Closure Cap Cost (M)	Total Relative Closure Cost [1] (M)
ISC, WSF/SCF, and DPD	1.7	3.8	32.5	0	1.4	39.3
ISC, WSF/SCF, DPD, and SDC	1.7	3.8	32.5	1.1	1.4	40.4
ISC, WSF/SCF, DPD, and TDC	1.7	3.8	32.5	2.0	1.4	41.3

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Traditional Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Traditional Method [2] ($M)	Total Relative Cost – Traditional Method [3] ($M)
ISC, WSF/SCF, and DPD	58.2	2.9	61.1	100.4
ISC, WSF/SCF, DPD, and SDC	45.6	1.4	47.0	87.5
ISC, WSF/SCF, DPD, and TDC	32.9	1.4	34.4	75.7

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Cap Replacement Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Cap Replacement Method [2] ($M)	Total Relative Cost – Cap Replacement Method [3] ($M)
ISC, WSF/SCF, and DPD	19.9	2.9	22.8	62.1
ISC, WSF/SCF, DPD, and SDC	7.9	1.4	9.3	49.7
ISC, WSF/SCF, DPD, and TDC	5.7	1.4	7.1	48.5

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 21. Cost per Subsidence Reduction and Cost per Volume of Waste Received Summary

Waste/Subsidence Treatment Method	Closure Cost per Subsidence Reduction (M / %)	Long-term Maintenance Cost – Traditional Method per Subsidence Reduction (M / %)	Total Cost – Traditional Method per Subsidence Reduction (M / %)	Total Cost – Traditional Method per Volume of Waste Received ($/m^3)
ISC, WSF/SCF, and DPD	1.11	1.72	2.83	1,908
ISC, WSF/SCF, DPD, and SDC	0.82	0.95	1.77	1,662
ISC, WSF/SCF, DPD, and TDC	0.65	0.54	1.19	1,439
Waste/Subsidence Treatment Method	**Closure Cost per Subsidence Reduction ($M / %)**	**Long-term Maintenance Cost –Cap Replacement Method per Subsidence Reduction ($M / %)**	**Total Cost – Traditional Method per Subsidence Reduction ($M / %)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/m^3)**
ISC, WSF/SCF, and DPD	1.11	0.64	1.75	1,180
ISC, WSF/SCF, DPD, and SDC	0.82	0.19	1.00	945
ISC, WSF/SCF, DPD, and TDC	0.65	0.11	0.76	921

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

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5.0 SUMMARY

The previous Phifer and Wilhite (2001) study evaluated six waste/subsidence treatment methods relative to subsidence potential reduction and cost. From that study the following two waste/subsidence treatment methods were determined to be most technically effective and cost efficient of the methods evaluated in that study:

- Tertiary Dynamic Compaction Case: Tertiary dynamic compaction (TDC) of uncompacted B-25 boxes stacked within an Engineered Trench that had received an interim soil cover (ISC and TDC)
- Combined Case: Tertiary dynamic compaction of stacked B-25 boxes that have been processed through the WSF/SCF within an Engineered Trench that had received an interim soil cover (ISC, TDC, and WSF/SCF)

This study evaluated an additional three waste/subsidence treatment methods relative to subsidence potential reduction and cost (see section 4.14). From this study the following waste/subsidence treatment method was determined to be most technically effective and cost efficient of the three methods evaluated:

> Direct Puck Disposal Case: Placement of uncompacted B-25s with direct disposed pucks on top in an Engineered Trench that is then covered with an interim soil cover and receives tertiary dynamic compaction (ISC, WSF/SCF, DPD, and TDC)

While direct puck disposal represents the optimal subsidence treatment achievable through use of the WSF/SCF, SWD does not consider it a realistic disposal option due to contamination control and personnel safety concerns associated with this case. Therefore it is viewed as a sensitivity case representing the optimal possible use of WSF/SCF for subsidence treatment.

Table 22, Table 23, and Table 24 present a comparison of these three best cases from the Phifer and Wilhite (2001) study and this study. Table 22 presents a summary of the relative subsidence potential and other pertinent parameters for these three cases. Table 23 presents a summary of the relative costs for these three cases. Table 24 presents a summary of the cost per subsidence reduction and cost per volume of waste received for these three cases. The following conclusions were drawn on the basis of subsidence potential reduction, cost, cost per subsidence reduction, and cost per volume of waste received for disposal from these tables:

- The direct puck disposal case (ISC, WSF/SCF, DPD, and TDC) reduces the relative subsidence potential by 11 percent (20 inches) and 7 percent (13 inches) over the tertiary dynamic compaction case (ISC and TDC) and combined case (ISC, TDC, and WSF/SCF), respectively.
- The direct puck disposal case reduces the number of B-25 boxes utilized by 13,368 and 4,728 boxes over the tertiary dynamic compaction and combined cases, respectively.

- The direct puck disposal case reduces the Engineered Trench and the closure cap surface areas by approximately 45 percent and 8 percent over the tertiary dynamic compaction and combined cases, respectively.
- The tertiary dynamic compaction case has the lowest total relative closure cost and the lowest closure cost per subsidence reduction than the other two cases.
- The direct puck disposal case has the lowest long-term maintenance cost and the lowest long-term maintenance cost per subsidence reduction than the other two cases. The direct puck disposal case has the lowest subsidence repair cost, since it results in a slightly greater reduction in subsidence potential and utilizes an Engineered Trench with less surface area than the other two cases.
- The case with the lowest total cost, lowest total cost per subsidence reduction, and lowest cost per volume of waste received for disposal depends upon which subsidence repair method is utilized. If the traditional subsidence repair method is utilized, the direct disposal case is lowest, however if the cap replacement method is utilized, the tertiary dynamic compaction case is lowest.
- For both the traditional and the cap replacement subsidence repair methods, the tertiary dynamic compaction case has the lowest up front costs and the highest long-term costs versus the other two cases.

The direct puck disposal case represents the optimal subsidence treatment that can possibly be achieved with supercompaction (WSF/SCF), in terms of both subsidence potential reduction and total cost. However, this case still has a significant subsidence potential of 5.5 feet, which is due to disposal of uncompactable waste in B-25 boxes. This continues to support the previous conclusion in Phifer and Wilhite (2001) that the use of B-25 boxes results in large inherent subsidence potential which cannot be totally eliminated by any of the methods evaluated. All of the waste/subsidence treatment methods evaluated are simply efforts that try to reduce the subsidence impacts created by the use of B-25 boxes.

The direct puck disposal case (ISC, WSF/SCF, DPD, and TDC) significantly reduces the use of B-25 boxes. Rather than placing the supercompacted pucks in B-25 boxes for disposal, the pucks are assumed to be disposed directly in the Engineered Trench. For this case, B-25 boxes are only utilized for the disposal of the uncompactable waste fraction. However the uncompactable waste fraction still represents a significant usage of B-25 boxes, and the direct puck disposal case still utilizes the Waste Sort Facility / Super Compactor Facility (WSF/SCF), which represents a significant short-term cost. The use of soft-sided bags (SSB), rather than the use of the WSF/SCF, for disposal of the compactable waste fraction may represent an opportunity to significantly decrease the short-term costs, while at the same time maintaining relatively low long-term costs. Evaluation of the SSB should continue and include an economic evaluation versus continued use of the WSF/SCF.

Overall this supplemental sensitivity study does not significantly change the conclusions and recommendations presented in Phifer and Wilhite (2001). Therefore, the Phifer and Wilhite (2001) conclusions and recommendations remain applicable.

Table 22. Relative Subsidence Potential and Other Pertinent Parameters Summary

Subsidence Treatment Method	Relative Subsidence Potential (ft)	Relative Subsidence Potential Reduction (%)	Subsidence Period (years)
Base Subsidence Potential [1]	15.1	0	NA
ISC and TDC [1]	7.2	52.4	100 - 150
ISC, WSF/SCF, and TDC [1]	6.6	56.3	100 - 150
ISC, WSF/SCF, DPD, and TDC	5.52	63.5	100 – 150
Subsidence Treatment Method	**Number of B-25 Boxes Used**	**Engineered Trench Surface Area (acres)**	**Closure Cap Surface Area (acres)**
ISC and TDC [1]	20,640	3.85	4.28
ISC, WSF/SCF, and TDC [1]	12,000	2.24	2.61
ISC, WSF/SCF, DPD, and TDC	7,272	2.06	2.40

[1] Phifer and Wilhite, 2001

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 23. Relative Cost Summary

Waste/ Subsidence Treatment Method	Engineered Trench Cost (M)	B-25 Box Cost ($M)	WSF/SCF Cost ($M)	Dynamic Compaction Cost ($M)	Closure Cap Cost ($M)	Total Relative Closure Cost ($M)
ISC and TDC [1]	3.1	10.8	0.0	3.6	2.4	19.9
ISC, WSF/SCF, and TDC [1]	1.8	6.3	32.5	2.2	1.5	44.2
ISC, WSF/SCF, DPD, and TDC	1.7	3.8	32.5	2.0	1.4	41.3

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Traditional Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Traditional Method ($M)	Total Relative Cost – Traditional Method ($M)
ISC and TDC [1]	80.3	1.7	82.0	101.9
ISC, WSF/SCF, and TDC [1]	41.5	1.5	43.0	87.2
ISC, WSF/SCF, DPD, and TDC	32.9	1.4	34.4	75.7

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Cap Replacement Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Cap Replacement Method ($M)	Total Relative Cost – Cap Replacement Method ($M)
ISC and TDC [1]	12.9	1.7	14.7	34.5
ISC, WSF/SCF, and TDC [1]	7.4	1.5	8.8	53.1
ISC, WSF/SCF, DPD, and TDC	5.7	1.4	7.1	48.5

[1] Phifer and Wilhite, 2001

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

Table 24. Cost per Subsidence Reduction and Cost per Volume of Waste Received Summary

Waste/Subsidence Treatment Method	Closure Cost per Subsidence Reduction ($M / %)	Long-term Maintenance Cost – Traditional Method per Subsidence Reduction ($M / %)	Total Cost – Traditional Method per Subsidence Reduction ($M / %)	Total Cost – Traditional Method per Volume of Waste Received ($/m^3)
ISC and TDC [1]	0.4	1.6	1.9	1,936
ISC, WSF/SCF, and TDC [1]	0.8	0.8	1.5	1,657
ISC, WSF/SCF, DPD, and TDC	0.65	0.54	1.19	1,439
Waste/Subsidence Treatment Method	**Closure Cost per Subsidence Reduction (M / %)**	**Long-term Maintenance Cost –Cap Replacement Method per Subsidence Reduction (M / %)**	**Total Cost – Traditional Method per Subsidence Reduction (M / %)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/m^3)**
ISC and TDC [1]	0.4	0.3	0.7	656
ISC, WSF/SCF, and TDC [1]	0.8	0.2	0.9	1,008
ISC, WSF/SCF, DPD, and TDC	0.65	0.11	0.76	921

[1] Phifer and Wilhite, 2001

ISC = Interim Soil Cover; WSF/SCF = Waste Sort Facility / Super Compactor Facility;
DPD = Direct Puck Disposal; SDC = Standard Dynamic Compaction; TDC = Tertiary Dynamic Compaction

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6.0 REFERENCES

Phifer, M. A. and Wilhite, E. L., "Waste Subsidence Potential versus Supercompaction," WSRC-RP-2001-00613, Savannah River Site, Aiken, SC 29808 (2001).

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APPENDIX A

DIRECT PUCK DISPOSAL CALCULATIONS

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APPENDIX A

DIRECT PUCK DISPOSAL CALCULATIONS

LIST OF TABLES

APPENDIX A

DIRECT PUCK DISPOSAL CALCULATIONS

Cases under Evaluation

The following are supplemental cases to those presented in Phifer and Wilhite (2001), which are evaluated within this document:

- ISC, WSF/SCF, and DPD = Processing through the Waste Sort Facility/Super Compactor Facility (WSF/SCF) with direct puck disposal (DPD; i.e. pucks are not contained in a B-25 box) on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC)
- ISC, WSF/SCF, DPD, and SDC = Processing through the WSF/SCF with DPD on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC) followed by standard dynamic compaction (SDC)
- ISC, WSF/SCF, DPD, and TDC = Processing through the WSF/SCF with DPD on top of B-25 boxes containing uncompactable wastes stacked within an Engineered Trench covered with an interim soil cover (ISC) followed by tertiary dynamic compaction (TDC)

The above acronyms in addition to those presented below will be utilized throughout the rest of these calculations:

- ISC = Interim Soil Cover
- WSF/SCF = Waste Sort Facility / Super Compactor Facility
- DPD = Direct Puck Disposal
- SDC = Standard Dynamic Compaction
- TDC = Tertiary Dynamic Compaction

Equivalence to Previous Study (Phifer and Wilhite, 2001) Calculations

- It is assumed that the height of disposal remains the same (i.e. total waste and container thickness of approximately 17.3 feet), and therefore there is a direct, one to one correspondence between volume and area reductions.
- An Engineered Trench filled with B-25 Boxes processed through the Waste Sort Facility / Super Compactor Facility (WSF/SCF) has a surface area of 2.24 acres and requires a closure cap with a surface area of 2.61 acres.
- On the average, 40 pucks are contained in a supercompacted B-25 box.
- Of the 12,000 B-25s in an Engineered Trench containing both supercompacted B-25s and uncompacted B-25s, 4,728 are supercompacted B-25s and 7,272 are uncompacted B-25s.
- It is assumed that the pucks are 2-foot diameter and 0.5- foot thick..
- The exterior dimensions of a B-25 box are as follows: 4.323-foot height, 6.078-foot length, and 3.9115-foot width. The interior dimensions of a B-25 box are as follows: 3.917-foot height, 6.0-foot length, and 3.833-foot width.
- It is assumed that the pucks inside supercompacted B-25s are stacked to within 6 inches (0.5 feet) of the box lid.
- Equivalent number of pucks in a direct puck disposal Engineered Trench to an Engineered Trench containing both supercompacted B-25s and uncompacted B-25s:

Equivalent number of pucks $= 4{,}728 \text{ B-25s} \times 40 \text{ pucks per B-25}$

$= 189{,}120 \text{ pucks}$

- Total puck volume (excluding voids between pucks):

Total puck volume $= 189{,}120 \text{ pucks} \times (0.5 \text{ ft} \times \pi \times (1 \text{ ft})^2 \text{ per puck})$

$= 297{,}069 \text{ ft}^3$

- Exterior B-25 box volume $= 4.323 \text{ ft} \times 6.078 \text{ ft} \times 3.9115 \text{ ft}$

$= 102.775 \text{ ft}^3$

- Volume of pucks in a B-25 box $= (3.917 \text{ ft} - 0.5 \text{ ft}) \times 6.0 \text{ ft} \times 3.833 \text{ ft}$

$= 78.584 \text{ ft}^3$

- Percent volume reduction by not using B-25s for pucks:

  Percent volume reduction $= ((102.775 - 78.584) \div 102.775) \times 100$

  $= 23.5\%$

  Will reduce this volume reduction to 20% to account for some inefficiency in puck packing when the pucks are randomly dumped with soil on top of the uncompacted B-25s.

- Puck volume equivalent number of B-25s $= 4{,}728 \times (1.00 - 0.20)$

  $= 3{,}782$

- Total volume equivalent number of B-25s $= 3{,}782 + 7{,}272$

  $= 11{,}054$

- Percent reduction in total B-25s $= (11{,}054 \div 12{,}000) \times 100$

  $= 92.1\%$

- Engineered Trench surface area $= 0.921 \times 2.24$ acres

  $= 2.06$ acres

- Closure Cap surface area **= 0.921 × 2.61 ACRES**

  $= 2.40$ acres

- Percent puck and void volumes:
  - Percent puck volume $= (297{,}069 \text{ ft} \div (3782 \times 102.775)) \times 100$
  - $= 76\%$

  - Percent void volume $= 100\% - 76\%$

    $= 24\%$

  This void volume looks reasonable, and it is assumed that this void volume is filled with soil.

Table 1. Equivalence to Previous Study (Phifer and Wilhite, 2001) Summary

Waste/Subsidence Treatment Method	Number of Uncompacted B-25 Boxes[1]	Equivalent Number of Supercompacted B-25s	Equivalent number of pucks	Puck Volume Equivalent Number of B-25 Boxes
ISC, WSF/SCF, and DPD	7,272	4,728	189,120	3,782
ISC, WSF/SCF, DPD, and SDC	7,272	4,728	189,120	3,782
ISC, WSF/SCF, DPD, and TDC	7,272	4,728	189,120	3,782
Waste/Subsidence Treatment Method	**Puck Volume Equivalent Total Number of B-25 Boxes**	**Engineered Trench Surface Area (acres)**	**Closure Cap Surface Area (acres)**	**Subsidence Period (years)**
ISC, WSF/SCF, and DPD	11,054	2.06	2.40	200 to 300
ISC, WSF/SCF, DPD, and SDC	11,054	2.06	2.40	100 to 150
ISC, WSF/SCF, DPD, and TDC	11,054	2.06	2.40	100 to 150

[1] This is also the number of B-25 boxes used and disposed.

Relative Subsidence Potential and Subsidence Potential Reduction Calculations

- It is assumed that the puck and soil zone has a density of 1.5 g/cm^3 and is therefore not subject to subsidence.
- The density of the uncompacted B-25s is 0.2067 g/cm^3.
- Of the 11,054 total equivalent B-25s in an Engineered Trench containing both direct disposed pucks and uncompacted B-25s, 3,782 are puck volume equivalent B-25s and 7,272 are uncompacted B-25s.
- It is assumed that the B-25s/waste will eventually compact to an average bulk density of 1.5 g/cm^3.
- The interior height of a B-25 box is 3.917 feet.
- The subsidence potential due to the risers on a stack of four B-25 boxes is assumed to be 1.312 feet.

- The maximum subsidence potential reduction that can be produced from the dynamic compaction of a stack of four uncompacted B-25 boxes is 6.427 feet (not considering the treatment surface area).
- Standard dynamic compaction results in the treatment of 50% of the surface area.
- Tertiary dynamic compaction results in the treatment of essentially 100% of the surface area.

- Average waste density

$$= \frac{((1.5\ g/cm^3 \times 3782) + (0.2067\ g/cm^3 \times 7272))}{(3782 + 7272)}$$

$$= 0.649\ g/cm^3$$

- Fraction of waste subject to subsidence

$$= 7272 \div (3782 + 7272)$$

$$= 0.658$$

- ISC, WSF/SCF, and DPD subsidence potential

$$= (4 \times \frac{(1.5\ g/cm^3 - 0.649\ g/cm^3)}{1.5\ g/cm^3} \times 3.917\ ft) + (0.658 \times 1.312\ ft)$$

$$= 9.75\ ft$$

- ISC, WSF/SCF, DPD, and SDC subsidence potential

$$= 9.75\ ft - (0.5 \times (0.658 \times 6.427))$$

$$= 7.64\ ft$$

- ISC, WSF/SCF, DPD, and TDC subsidence potential

$$= 9.75\ ft - (1.0 \times (0.658 \times 6.427))$$

$$= 5.52\ ft$$

Table 2. Estimated Relative Subsidence Potential and Subsidence Potential Reduction Calculations

Waste/Subsidence Treatment Method	Estimated Relative Subsidence Potential (ft)	Estimated Relative Subsidence Potential Reduction (%)
Base Subsidence Potential [1]	15.116	$= \frac{15.116 - 15.116}{15.116} \times 100 = 0$
ISC, WSF/SCF, and DPD	9.75	$= \frac{15.116 - 9.75}{15.116} \times 100 = 35.5$
ISC, WSF/SCF, DPD, and SDC	7.64	$= \frac{15.116 - 7.64}{15.116} \times 100 = 49.5$
ISC, WSF/SCF, DPD, and TDC	5.52	$= \frac{15.116 - 5.52}{15.116} \times 100 = 63.5$

[1] Subsidence Potential of a stack of four uncompacted B-25 boxes prior to the placement of the interim soil cover from WSRC--RP-2001-00613

Relative Subsidence Potential and Subsidence Potential Reduction Calculations

- Cost of Engineered Trench design and construction for one 12,000 B-25 Box Engineered Trench is $1,800,000.
- Total Equivalent number of B-25s for cases involving the disposal of loose pucks (i.e. pucks are not placed in B-25s) is 11,054.
- A direct linear relationship is assumed between the design and construction cost and the equivalent number of B-25s to be disposed for each case under consideration.
- Design and Construction Cost for one 11,054 B-25 Box Engineered Trench:

Design and Construction Cost = \$1,800,000 × (11,054 ÷ 12,000)

= \$1,658,100

Table 25. Relative Cost of Engineered Trench Design and Construction Summary

Waste/Subsidence Treatment Method	Volume Equivalent Number of B-25 Boxes Disposed	Relative Engineered Trench Design and Construction Cost ($)
ISC, WSF/SCF, and DPD	11,054	1,658,100
ISC, WSF/SCF, DPD, and SDC	11,054	1,658,100
ISC, WSF/SCF, DPD, and TDC	11,054	1,658,100

Relative Waste/Subsidence Treatment Method Costs Calculations

- The cost of B-25 boxes is not included in the WSF/SCF costs, however the cost of 55-gallon drums is included.
- Each B-25 box costs $523.
- It is assumed that the WSF/SCF cost will not substantially change by not using B-25 boxes to place the pucks in after super compaction.
- WSF/SCF cost are equivalent to $6,876 / supercompacted B-25 box.
- Of the 12,000 B-25s in an Engineered Trench containing both supercompacted B-25s and uncompacted B-25s, 4,728 are supercompacted B-25s and 7,272 are uncompacted B-25s.
- Based upon a previous assumption and calculation, an Engineered Trench containing uncompacted B-25s and loose pucks, which have been processed through the WSF/SCF, will be taken as containing a total volume equivalent 11,054 B-25s and will be taken as having a surface area of 2.06 acres.

- Based upon a previous calculation, of the 11,054 volume equivalent B-25s in an Engineered Trench containing uncompacted B-25s and loose pucks processed through the WSF/SCF, there are 7,272 B-25s containing uncompacted waste and a volume equivalent 3,782 B-25s of loose pucks.
- Based upon past SRS experience the subcontractor costs for performance of standard dynamic compaction has been estimated at $100,000 for mobilization/demobilization plus $200,000 per acre.
- The total Standard Dynamic Compaction cost is assumed to be 2 times the subcontractor cost to account for the indirect cost.
- Standard dynamic compaction treats only 50% of the area whereas tertiary dynamic compaction treats 100% of the area. Therefore since standard dynamic compaction has been estimated to cost $200,000 per acre, tertiary dynamic compaction will be assumed to cost $400,000 per acre. Mobilization/demobilization costs will be assumed to remain at $100,000 for tertiary dynamic compaction.

Table 4. Calculated B-25 Box Costs for Each Case

Waste/Subsidence Treatment Method	**Number of B-25s used and Disposed**	**Calculated B-25 Box Cost ($)**
ISC, WSF/SCF, and DPD	7,272	$= 7{,}272 \times \$523 = \$3{,}803{,}256$
ISC, WSF/SCF, DPD, and SDC	7,272	$= 7{,}272 \times \$523 = \$3{,}803{,}256$
ISC, WSF/SCF, DPD, and TDC	7,272	$= 7{,}272 \times \$523 = \$3{,}803{,}256$

Table 5. Calculated WSF/SCF Waste/Subsidence Treatment Method Costs for Each Case

Waste/Subsidence Treatment Method	**Equivalent Number of Super-compacted of B-25s**	**Calculated WSF/SCF Cost ($)**
ISC, WSF/SCF, and DPD	4,728	$= 4{,}728 \times \$6{,}876 = \$32{,}509{,}728$
ISC, WSF/SCF, DPD, and SDC	4,728	$= 4{,}728 \times \$6{,}876 = \$32{,}509{,}728$
ISC, WSF/SCF, DPD, and TDC	4,728	$= 4{,}728 \times \$6{,}876 = \$32{,}509{,}728$

Table 6. Calculated Dynamic Compaction Waste/Subsidence Treatment Costs for Each Case

Waste/Subsidence Treatment Method	Engineered Trench Surface Area (acres)	Calculated Dynamic Compaction Cost ($)
ISC, WSF/SCF, and DPD	2.06	0
ISC, WSF/SCF, DPD, and SDC	2.06	**= (2 × ($100,000 + (2.06 AC × $200,000/AC))) × 1.0927 = $1,118,925**
ISC, WSF/SCF, DPD, and TDC	2.06	**= (2 × ($100,000 + (2.06 AC × $400,000/AC))) × 1.0927 = $2,019,310**

The dynamic compaction costs have been escalated from 1998 to 2001 based upon a yearly 3% inflation rate (3 years at a F/P factor of 1.0927).

Relative Closure Cap Cost Calculations

- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer.
- It is assumed that the cost of the FML/GCL closure caps can be determined from the estimated closure cap construction costs of a 2- and 5-acre cap at $894,156 and $2,206,378 as determined from a 1993 study.
- A direct linear relationship is assumed between cost and the acreage of the closure cap.
- Based upon a previous calculation the closure cap surface area is 2.40 acres over an Engineered Trench containing both direct disposed pucks and uncompacted B-25s.
- Cost of a closure cap over an Engineered Trench containing both direct disposed pucks and uncompacted B-25s:

The cost has been escalated from 1993 to 2001 based upon a yearly 3% inflation rate (8 years at a F/P factor of 1.2668).

$$\text{Closure Cap Cost} = 1.2668 \times (\$894{,}156 + ((\$2{,}206{,}378 - \$894{,}156) \times \frac{(2.40 - 2)}{(5 - 2)}))$$

$$= \$1{,}354{,}360$$

Table 7. Relative GML/GCL Closure Cap Cost Summary

Waste/Subsidence Treatment Method	Closure Cap Surface Area (acres)	Relative FML/GCL Closure Cap Cost ($)
ISC, WSF/SCF, and DPD	2.40	1,354,360
ISC, WSF/SCF, DPD, and SDC	2.40	1,354,360
ISC, WSF/SCF, DPD, and TDC	2.40	1,354,360

Relative Closure Cap Subsidence Repair Costs Calculations – Traditional Method

- It is assumed that subsidence will occur over the entire surface area of the closure cap, which is directly over the Engineered Trench, over the subsidence period.
- It is assumed that the number of traditional repair events per area will be proportional to the subsidence potential. It is further assumed that every four feet of subsidence will produce a condition, requiring repair. Therefore, the number of repair events is assumed to equal the estimated relative subsidence potential divided by four feet. It is assumed that fractions of 4 feet will also require repair due to the extended nature of the subsidence periods.
- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer.
- A traditional repair cost of $266/ft^2 for a FML/GCL closure cap is assumed.
- The Relative Traditional Cap Subsidence Repair Cost is assumed to equal the following:

$$\text{Traditional Repair Cost} = \$266/\text{ ft}^2 \times \text{Number of Repair Events} \times \text{Surface Area (ft}^2\text{)}.$$

- Based upon a previous calculation the Engineered Trench surface area is 2.06 acres (2.06 acres $\times$ 43560 ft^2/acre = 89,734 ft^2) over an Engineered Trench containing both direct disposed pucks and uncompacted B-25s.
- Table provides the estimated relative subsidence potential, assumed subsidence period, and the surface area of the Engineered Trench. The values in the table are based upon previous calculations and assumptions.

Table 8. Engineered Trench Parameters

Waste/Subsidence Treatment Method	Relative Subsidence Potential (ft)	Engineered Trench Surface Area (ft^2)
ISC, WSF/SCF, and DPD	9.75	89,734
ISC, WSF/SCF, DPD, and SDC	7.64	89,734
ISC, WSF/SCF, DPD, and TDC	5.52	89,734

- The number of traditional repair events has been calculated by dividing the estimated relative subsidence potential by four feet in Table .

Table 9. Number of Traditional Repair Events

Waste/Subsidence Treatment Method	Relative Subsidence Potential (ft)	Number of Traditional Repair Events
ISC, WSF/SCF, and DPD	9.75	9.75 ft ÷ 4 ft = 2.44
ISC, WSF/SCF, DPD, and SDC	7.64	7.64 ft ÷ 4 ft = 1.91
ISC, WSF/SCF, DPD, and TDC	5.52	5.52 ft ÷ 4 ft = 1.38

- Relative Traditional Cap Subsidence Repair Cost has been calculated in the following table based upon the following formula:

Traditional Repair Cost = $\$266/\text{ ft}^2 \times$ Number of Repair Events $\times$ Surface Area (ft^2)

Table 10. Relative Traditional Cap Subsidence Repair Cost

Waste/Subsidence Treatment Method	Number of Traditional Repair Events	Engineered Trench Surface Area (ft^2)	Relative Closure Cap Subsidence Repair Cost - Traditional Method ($)
ISC, WSF/SCF, and DPD	2.44	89,734	= $\$266/\text{ ft}^2 \times 2.44 \times 89{,}734\text{ ft}^2$ **= $58,240,955**
ISC, WSF/SCF, DPD, and SDC	1.91	89,734	= $\$266/\text{ ft}^2 \times 1.91 \times 89{,}734\text{ ft}^2$ = $45,590,256
ISC, WSF/SCF, DPD, and TDC	1.38	89,734	= $\$266/\text{ ft}^2 \times 1.38 \times 89{,}734\text{ ft}^2$ = $32,939,557

Relative Closure Cap Subsidence Repair Costs Calculations – Cap Replacement Method

- For B-25s that are not dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 200 to 300 years after burial.
- For B-25s that are dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 100 to 150 years after burial and dynamic compaction.

- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer.
- It is assumed that subsidence will occur over the entire surface area of the closure cap, which is directly over the Engineered Trench, over the subsidence period.
- It is assumed that rather than repairing the closure cap at each subsidence event, as done under the traditional methodology, the following will be performed:
    - Subsidence holes will be filled in with soil to maintain the grade and promote runoff as they occur. The costs associated with this activity are considered to be covered in the cost estimate for the cap replacements, since these costs include site pre-contouring and foundation soil placement costs.
    - The entire cap will be replaced periodically during the duration of subsidence. The frequency of cap replacement will be based upon the relative subsidence potential associated with each case. It is assumed that the cap replacement frequency varies inversely with relative subsidence potential. The cap replacement frequency for the ISC, WSF/SCF and TDC case will be assumed to be 10 years; all other cap replacement frequencies will be determined based upon this case. The old cap will not be removed, but a new cap will be placed directly on top of the old cap.
- Based upon a previous calculation the cost of a 2.40-acre FML/GCL closure cap is assumed to be $1,354,360.

Table 11. Relative Subsidence Potential, Subsidence Period, and Closure Cap Surface Area

Waste/Subsidence Treatment Method	Subsidence Period (years)	Relative Subsidence Potential (ft)	Closure Cap Surface Area (acres)
ISC, WSF/SCF, and DPD	200 to 300	9.75	2.40
ISC, WSF/SCF, DPD, and SDC	100 to 150	7.64	2.40
ISC, WSF/SCF, DPD, and TDC	100 to 150	5.52	2.40

Values in the table are based upon previous calculations and assumptions.

Table 12. Assumed Duration Of Subsidence During Which the Cap Will Be Replaced

Waste/Subsidence Treatment Method	Subsidence Period (years)	Duration of Subsidence (years)
ISC, WSF/SCF, and DPD	200 to 300	300 – 200 = 100
ISC, WSF/SCF, DPD, and SDC	100 to 150	150 – 100 = 50
ISC, WSF/SCF, DPD, and TDC	100 to 150	150 – 100 = 50

Waste/Subsidence Treatment Method	Relative Subsidence Potential (ft)	Cap Replacement Frequency [1] (years)
ISC, WSF/SCF, and DPD	9.75	**= (6.601 FT ÷ 9.75 FT) 10 YEARS** = 6.8 years
ISC, WSF/SCF, DPD, and SDC	7.64	= (6.601 ft ÷ 7.64 ft) 10 years = 8.6 years
ISC, WSF/SCF, DPD, and TDC	5.52	= (6.601 ft ÷ 5.52 ft) 10 years = 12.0 years

[1] FROM PHIFER AND WILHITE (2001) THE ISC, WSF/SCF, AND TDC CASE HAS A SUBSIDENCE POTENTIAL OF 6.601 FT AND A CAP REPLACEMENT FREQUENCY OF 10 YEARS IS ASSUMED. THIS IS THE BASIS FOR THE DETERMINATION OF CAP REPLACEMENT FREQUENCIES FOR OTHER CASES.

Table 13. Number of Cap Replacements

Waste/Subsidence Treatment Method	Duration of Subsidence (years)	Cap Replacement Frequency (years)	Number of Replacement Caps
ISC, WSF/SCF, and DPD	100	6.8	100 ÷ 6.8 = 14.7
ISC, WSF/SCF, DPD, and SDC	50	8.6	**50 ÷ 8.6** = 5.8
ISC, WSF/SCF, DPD, and TDC	50	12.0	50 ÷ 12.0 = 4.2

Table 14. Cost of Cap Replacement Subsidence Repair Calculations

Waste/Subsidence Treatment Method	Number of Replacement Caps	Cost per Replacement Cap ($)	Relative Cap Subsidence Repair Cost - Cap Replacement Method ($)
ISC, WSF/SCF, and DPD	14.7	1,354,360	14.7 × 1,354,360 = 19,909,092
ISC, WSF/SCF, DPD, and SDC	5.8	1,354,360	5.8 × 1,354,360 = 7,855,288
ISC, WSF/SCF, DPD, and TDC	4.2	1,354,360	4.2 × 1,354,360 = 5,688,312

Relative Cumulative Operating and Maintenance Cost Calculations

- Based upon previous calculations and assumptions, the closure cap over an Engineered Trench containing direct disposal pucks and uncompacted B-25s has a surface area of 2.40 acres.
- It is assumed that Operating and Maintenance (O&M) costs will be incurred until the subsidence period for each case has been completed.
- For B-25s that are not dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 200 to 300 years after burial.
- For B-25s that are dynamically compacted a period of B-25 box structural collapse (i.e. a subsidence period) has been assumed to be from 100 to 150 years after burial and dynamic compaction.
- It is assumed that the closure cap over the Engineered Trench will consist of a high-density polyethylene (HDPE), flexible membrane liner (FML) over a geosynthetic clay liner (GCL) over a clayey sand foundation layer.
- It is assumed that the Operating and Maintenance costs associated with FML/GCL closure caps can be determined from the 2- and 5-acre cap estimates at $7,200 and $9,700, respectively, from a 1993 study.
- A direct linear relationship is assumed between cost and the acreage of the closure cap.
- The yearly O&M cost for a closure cap has been calculated as follows:

Closure Cap Acreage = 2.40 acres

THE COST HAS BEEN ESCALATED FROM 1993 TO 2001 BASED UPON A YEARLY 3% INFLATION RATE
(8 YEARS AT A F/P FACTOR OF 1.2668)

Yearly O&M Cost $= 1.2668 \times (\$7{,}200 + ((\$9{,}700 - \$7{,}200) \times \frac{(2.40 - 2)}{(5 - 2)}))$

= $9,543

Table 15. Closure Cap Surface Area, Yearly O&M Cost, and Subsidence Period

Waste/Subsidence Treatment Method	Closure Cap Surface Area (acres)	Yearly O&M Cost ($)	Subsidence Period (years)
ISC, WSF/SCF, and DPD	2.40	9,543	200 to 300
ISC, WSF/SCF, DPD, and SDC	2.40	9,543	100 to 150
ISC, WSF/SCF, DPD, and TDC	2.40	9,543	100 to 150

Table 16. Relative Cumulative O&M Cost

Waste/Subsidence Treatment Method	Relative Cumulative O&M Cost ($)
ISC, WSF/SCF, and DPD	= $9,543/year × 300 years = 2,862,900
ISC, WSF/SCF, DPD, and SDC	= $9,543/year × 150 years = 1,431,450
ISC, WSF/SCF, DPD, and TDC	= $9,543/year × 150 years = 1,431,450

Relative Cost per Subsidence Potential Calculations

Table 17. Closure Cost to Subsidence Potential, Reduction Ratio Calculations

Waste/Subsidence Treatment Method	Total Relative Closure Cost [1] (M)	Relative Subsidence Potential Reduction (%)	Closure Cost per Subsidence Potential Reduction [2] (M / %)
ISC, WSF/SCF, and DPD	39.3	35.5	1.11
ISC, WSF/SCF, DPD, and SDC	40.4	49.5	0.82
ISC, WSF/SCF, DPD, and TDC	41.3	63.5	0.65

[1] Total Closure Cost = Engineered Trench Cost + B-25 Box Cost + WSF/SCF Cost + Dynamic Compaction Cost + Closure Cap Cost

[2] Closure Cost per Subsidence Potential Reduction = Total Closure Cost ÷ Subsidence Potential Reduction

Table 18. Traditional Method Long-Term Maintenance Cost to Subsidence Potential Reduction Ratio Calculations

Waste/Subsidence Treatment Method	Total Relative Long-term Maintenance Cost [1] ($M)	Relative Subsidence Potential Reduction (%)	Long-term Maintenance Cost per Subsidence Potential Reduction [2] ($M / %)
ISC, WSF/SCF, and DPD	61.1	35.5	1.72
ISC, WSF/SCF, DPD, and SDC	47.0	49.5	0.95
ISC, WSF/SCF, DPD, and TDC	34.4	63.5	0.54

[1] Total Relative Long-term Maintenance Cost = Subsidence Repair Cost + Cumulative O&M Cost
[2] Long-term Maintenance Cost per Subsidence Potential Reduction = Total Long-term Maintenance Cost ÷ Subsidence Potential Reduction

Table 19. Traditional Method Total Cost to Subsidence Potential Reduction Ratio Calculations

Waste/Subsidence Treatment Method	Total Relative Cost [1] ($M)	Relative Subsidence Potential Reduction (%)	Total Cost per Subsidence Potential Reduction [2] ($M / %)
ISC, WSF/SCF, and DPD	100.4	35.5	2.83
ISC, WSF/SCF, DPD, and SDC	87.5	49.5	1.77
ISC, WSF/SCF, DPD, and TDC	75.7	63.5	1.19

[1] TOTAL RELATIVE COST = TOTAL RELATIVE CLOSURE COST + TOTAL RELATIVE LONG-TERM MAINTENANCE COST
[2] TOTAL COST PER SUBSIDENCE POTENTIAL REDUCTION = TOTAL COST ÷ SUBSIDENCE POTENTIAL REDUCTION

Table 20. Cap Replacement Method Long-Term Maintenance Cost to Subsidence Potential Reduction Ratio Calculations

Waste/Subsidence Treatment Method	Total Relative Long-term Maintenance Cost [1] ($M)	Relative Subsidence Potential Reduction (%)	Long-term Maintenance Cost per Subsidence Potential Reduction [2] ($M / %)
ISC, WSF/SCF, and DPD	22.8	35.5	0.64
ISC, WSF/SCF, DPD, and SDC	9.3	49.5	0.19
ISC, WSF/SCF, DPD, and TDC	7.1	63.5	0.11

[1] Total Relative Long-term Maintenance Cost = Subsidence Repair Cost + Cumulative O&M Cost
[2] Long-term Maintenance Cost per Subsidence Potential Reduction = Total Long-term O&M Cost ÷ Subsidence Potential Reduction

Table 21. Cap Replacement Method, Total Relative Cost to Subsidence Potential Reduction Ratio Calculations

Waste/Subsidence Treatment Method	Total Relative Cost – Cap Replacement Method [1] ($M)	Relative Subsidence Potential Reduction (%)	Total Cost per Subsidence Potential Reduction–Cap Replacement Method [2] ($M / %)
ISC, WSF/SCF, and DPD	62.1	35.5	1.75
ISC, WSF/SCF, DPD, and SDC	49.7	49.5	1.00
ISC, WSF/SCF, DPD, and TDC	48.5	63.5	0.76

[1] Total Relative Cost = Total Relative Closure Cost + Total Relative Long-term Maintenance Cost
[2] Total Cost per Subsidence Potential Reduction = Total Cost ÷ Subsidence Potential Reduction

Relative Total Cost per Volume of Waste Received Calculations

Table 22. Cost Per Volume of Waste Received for Disposal Calculations

Waste/Subsidence Treatment Method	Total Cost – Traditional Method ($)	Initial Volume (m^3)	Total Cost – Traditional Method per Volume of Waste Received ($/$m^3$)
ISC, WSF/SCF, and DPD	100,429,299	52,632	1,908
ISC, WSF/SCF, DPD, and SDC	87,466,075	52,632	1,662
ISC, WSF/SCF, DPD, and TDC	75,715,761	52,632	1,439
Waste/Subsidence Treatment Method	**Total Cost – Cap Replacement Method ($)**	**Initial Volume (m^3)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/$m^3$)**
ISC, WSF/SCF, and DPD	62,097,436	52,632	1,180
ISC, WSF/SCF, DPD, and SDC	49,731,107	52,632	945
ISC, WSF/SCF, DPD, and TDC	48,464,516	52,632	921

Total Cost per Volume of Waste Received = Total Cost ÷ Initial Volume

Relative Subsidence Potential and Cost Summary

Table 23. Relative Subsidence Potential and Subsidence Potential Reduction Summary

Subsidence Treatment Method	Relative Subsidence Potential (ft)	Relative Subsidence Potential Reduction (%)
ISC, WSF/SCF, and DPD	9.75	35.5
ISC, WSF/SCF, DPD, and SDC	7.64	49.5
ISC, WSF/SCF, DPD, and TDC	5.52	63.5

Table 24. Relative Cost Summary

Waste/ Subsidence Treatment Method	Engineered Trench Cost ($M)	B-25 Box Cost ($M)	WSF/SCF Cost ($M)	Dynamic Compaction Cost (M)	Closure Cap Cost ($M)	Total Relative Closure Cost [1] ($M)
ISC, WSF/SCF, and DPD	1.7	3.8	32.5	0	1.4	39.3
ISC, WSF/SCF, DPD, and SDC	1.7	3.8	32.5	1.1	1.4	40.4
ISC, WSF/SCF, DPD, and TDC	1.7	3.8	32.5	2.0	1.4	41.3

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost – Traditional Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Traditional Method [2] ($M)	Total Relative Cost – Traditional Method [3] ($M)
ISC, WSF/SCF, and DPD	58.2	2.9	61.1	100.4
ISC, WSF/SCF, DPD, and SDC	45.6	1.4	47.0	87.5
ISC, WSF/SCF, DPD, and TDC	32.9	1.4	34.4	75.7

Waste/Subsidence Treatment Method	Relative Cap Subsidence Repair Cost –Cap Replacement Method ($M)	Cumulative O&M Cost ($M)	Total Relative Long-term Maintenance Cost – Cap Replacement Method [2] ($M)	Total Relative Cost – Cap Replacement Method [3] ($M)
ISC, WSF/SCF, and DPD	19.9	2.9	22.8	62.1
ISC, WSF/SCF, DPD, and SDC	7.9	1.4	9.3	49.7
ISC, WSF/SCF, DPD, and TDC	5.7	1.4	7.1	48.5

NOTE: All costs are rounded off to the nearest hundred thousand from the dollar values presented in the previous calculations. The total values are obtained by addition of its components in dollars and then rounded off to the nearest hundred thousand. Therefore, the total values in millions may not equal the addition of its components in millions as shown in the table.

[1] Total Closure Cost = Engineered Trench Cost + B-25 Box Cost + WSF/SCF Cost + Dynamic Compaction Cost + Closure Cap Cost

[2] Total Relative Long-term Maintenance Cost = Subsidence Repair Cost (Traditional or Cap Replacement) + Cumulative O&M Cost

[3] Total Relative Cost = Total Closure Cost + Total Relative Long-term Maintenance Cost

Table 25. Cost Per Subsidence Reduction and Cost Per Volume of Waste Received Summary

Waste/Subsidence Treatment Method	Closure Cost per Subsidence Reduction ($M / %)	Long-term Maintenance Cost – Traditional Method per Subsidence Reduction (M / %)	Total Cost – Traditional Method per Subsidence Reduction ($M / %)	Total Cost – Traditional Method per Volume of Waste Received ($/m^3)
ISC, WSF/SCF, and DPD	1.11	1.72	2.83	1,908
ISC, WSF/SCF, DPD, and SDC	0.82	0.95	1.77	1,662
ISC, WSF/SCF, DPD, and TDC	0.65	0.54	1.19	1,439
Waste/Subsidence Treatment Method	**Closure Cost per Subsidence Reduction ($M / %)**	**Long-term Maintenance Cost –Cap Replacement Method per Subsidence Reduction ($M / %)**	**Total Cost – Cap Replacement Method per Subsidence Reduction ($M / %)**	**Total Cost – Cap Replacement Method per Volume of Waste Received ($/m^3)**
ISC, WSF/SCF, and DPD	1.11	0.64	1.75	1,180
ISC, WSF/SCF, DPD, and SDC	0.82	0.19	1.00	945
ISC, WSF/SCF, DPD, and TDC	0.65	0.11	0.76	921

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